Organizational Results Research Report

October 2010
OR11.007

Light Detection and Ranging (LiDAR) Technology Evaluation

Prepared by
Sanborn Map Company,
HDR Engineering and Missouri
Department of Transportation

Final Report

TR 10-007

Light Detection and Ranging (LiDAR) Technology Evaluation

Prepared for
Missouri Department of Transportation
Organizational Results

by

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October 2010

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Executive Summary

The study TR10-007 Light Detection and Ranging (LiDAR) Technology Evaluation project was undertaken to provide an analysis on the current state of Laser based technology and its applicability, potential accuracies and information content with respect to Missouri Department of Transportation (MODOT) applications. This study involved collection of Airborne, Static (Terrestrial) and Mobile LiDAR over a known project area with existing control and check data sets and provides an assessment of accuracy, cost and feasibility for MODOT projects.

The mobile, aerial and static data sets meet the accuracy and information content required for geospatial information for mapping applications as well as additional information that can be mined for potential asset inventory and infrastructure information content.

The mobile technology allows for low risk and rapid collection of geospatial information, limiting safety impacts to workers, however there are limitations as to the range of the sensor and occlusions or shadowing affecting potential information content. The aerial LiDAR acting similar to traditional aerial imagery allowing for rapid collection of elevation information for detailed surface modeling as well as feature extraction using "LiDARgrammetry". The static system collects point cloud data, has more flexibility in scanning in "shadowed" areas from the mobile or aerial systems, but requires significantly more time and adds potential risk to the collection teams. All three technologies collect enormous amounts of point cloud data that proved extremely difficult to process and manage. Current software is limited in dealing with the mobile dataset in particular, requiring additional file creation and data management challenges. The mobile technology significantly reduces field collection time but increases back office processing, requiring potentially additional hardware and software to effectively manage the datasets. The software vendors must catch up to the hardware capability in order to reduce time and effort required to manage and extract useful information from the point clouds.

Mobile Mapping technology can provide a rich information dataset but is currently limited in its ability to be fully exploited due to software and processing limitations. However in order to collect surface elevations for contours, and base mapping features mobile mapping offers a safe, rapid complementary technology for DOT applications. Traditional survey or static scanning may still be required to fill any required information that may be "shadowed" by the mobile system, but the Mobile Mapping process can significantly lower costs and reduce worker safety risk.

Projects should be carefully scoped so that collection plans and data feature requirements are well defined, enabling concurrent field work if required. The accuracy of the LiDAR data and the speed at which it can be collected is a major benefit to the end user.

Contents

List of Figures

List of Tables

Introduction

The Missouri Department of Transportation (MoDOT) is interested in evaluating the advantages or disadvantages of data collection using Laser based technologies when compared to traditional photogrammetric or survey methods. MoDOT is interested in evaluating not only the technical aspects of information regarding this type of technology but also evaluating estimates on potential financial and schedule impacts and challenges for Laser Based Technology. Transportation officials desire to implement the most economical data collection method that meets the project requirements. Recently, Light Detection and Ranging (LiDAR) based mobile mapping technology draws lot of practitioners' attention, and has been recognized as an efficient and economic method for collecting various types of roadway asset data.

Mobile Laser Mapping has been in use in practical mapping studies that indicate its feasibility for survey applications.[1] These studies indicate that the speed, accuracy and information content that can be collected without impact to traffic or traditional survey safety concerns have the potential to provide cost and schedule benefits. Some of the key drivers for reviewing this technology with respect to MODOT operations are recently reported improvements in the overall accuracy of the technology, its application to support MODOT requirements, and the increased application of this technology.

This research will assess three different types of LiDAR data collection technology, and provide recommendations for the most viable data collection method based on results of the study. The LiDAR based mapping methods that will be evaluated in this research include:

a) Airborne LiDAR
b) Mobile Terrestrial LiDAR
c) Static Terrestrial LiDAR (3-D Scanning)

[1] *CLOSE PHOTOGRAMMETRY AND LASER SCANNING USING A MOBILE MAPPING SYSTEM FOR THE HIGH DETAILED SURVEY OF A HIGH DENSITY URBAN AREA The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B5. Beijing 2008*

Objectives

The key objectives for the project are to develop the following information as a result of the field data collection and post processing:

- Provide an error analysis matrix of TIN surfaces, features and control
- Provide a cost matrix detailing industry rates for collection and processing
- Provide a matrix of potential additional features or information that could be created from each technology

In addition as part of the report summary provides the following additional information:

- Field operations – basic procedures and note/records
- System calibration – pre and post collection procedures
- Operational pre & post collection methods and results
- Overview of post processing calibration and system checks.
- Feature collection methods – software and tools
- Quality control plan
- Matrix of feature and surface based accuracy assessment
- Matrix of schedule comparisons including planning times, field operations-collection flexibility, and data extraction
- Matrix of safety components and impacts

Present Conditions

Currently MODOT collects this mapping and road information using a combination of traditional aerial photogrammetric mapping supported by field surveys for aerial control. Detailed road cross sections are performed using traditional ground surveys and field crews. These methods although well understood and robust have potential issues with worker safety and traffic impact issues for collecting information on the road or near right of way. Additionally weather issues and traffic issues impact collection schedules and drive cost. These surveys also capture discreet or local point information for the immediate purpose of the survey. This potentially adds duplication of effort and cost if additional or other information is required in the same geographical area for other departments or uses.

Photogrammetry is a useful surveying tool for a few reasons. First, it allows the collection of visual data over a much larger area in a shorter period of time than can easily be surveyed at ground level by conventional means in a comparable amount of time. Second, the photographs offer a 3D representation of items and landmarks that may have changed over time, and possibly no longer exist as they once did. Surveyors are often times called upon to show that a specific object was in a particular location in respect to another object. While simple photographs cannot allow for the spatial differences, a 3D photogrammetric photo can. Third a 3D digital model is developed from the 3D photogrammetric photo. The photogrammetric image is an x-y-z model that has the added benefit of being fixed to a particular time and place. The digital processing of the imagery adds in GPS measurements to ensure the highest possible accuracy and GIS placement. The resulting digital terrain model created from the photogrammetric topographic survey is then used as a base for road cross sections, aerial mapping and design/build work.

As the mobile mapping technology has evolved to a point in the market where there is evidence that it provides potential benefit for mapping operations. MoDOT is seeking an evaluation of Laser based technology and its potential impact to the financial and safety aspects for it programs.

Literature Review and Publications - Print

Magazine	Date	PG	Relevance to The project
GIM International	Dec-09	22	Article on Definitions, applications and current Industry state on Airborne and Terrestrial Laser Scanning
GIM International	Feb-10	12,14	Article on University College of Dublin YobiLiDAR SW 3d Viewer
GIM International	Oct-09	77	Cloudworx AD for SmartPlant 3d – Sw for point cloud manipulation
GIM International	Jan-09	18	3Dlasermapping Ad on mobile scanning
POB	Feb-09	12,16	Application of Static scanning for runway and rail application, saftey and on site time benefits
GIS Development	Jun-09	41	Overview Aerial LiDAR and InSar applications
GEOConexion	Dec-09	33,38	Article e-cognitionfor LiDAR analyis
GEOConexion	Feb-10	13	Article 3D Laser Mapping China
GEOConexion	Mar-10	13,41	3D City modeling using Aerial LiDAR - Blom
Trimble Technology & More	Mar-09	13	Mobile Mapping for asset mapping – NetherlandS
Professional Surveyor	Jan-10	33	Article –Geoff Jacobs Laser Scanner Versatility Factors – overview of various applications and benifits
Professional Surveyor	Feb-10	16,26	Article Gorden Peery Mobile Mapping Overview – challenges in data management and processing
PE&RS	Mar-10	217,222	Mobile Mapping system overview – Geocue

These articles provided additional information and understanding on these technologies, uses, applications and solutions for collecting and using the data

Literature Review and Publications - Web

There are a number of web based GIS, Surveying Journals that provide information on technology trends and applications. As this technology continues to change and mature and the hardware in particular continues to develop, maintaining an awareness to new and near future hardware and software solutions and improvements are critical to execute these type of programs

A sampling of key web sites and organizations is listed below that provide on aerial and mobile mapping technology

American Congress on Surveying and Mapping (ACSM)	www.ascm.net
International Society for Photogrammetry (ISPRS),	www.isprs.org
American Society for Photogrammetry and Remote Sensing (ASPRS),	www.asprs.org
U.S. Department of Transportation, Federal Highway Administration,	www.fhwa.dot.gov
American Association of State Highway and Transportation Officials (AASHTO),	www.transportation.org
Transportation Research Board,	www.trb.org
Point of Beginning	www.pobonline.com
Asian Surveying & Mapping	www.asmmag.com
Cadalyst Magazine (Autodesk)	www.cadalyst.com
Directions Magazine	www.directionsmag.com
All Poin ts Blog	www.apbdirectionsmag.com
Geocommunity	www.geocomm.com
GeoConnexion	www.geoconnexion.com
Geoinformatics	www.geoinformatics.nl
Georeports	www.geoplace.com
GeoSpatial Solutions	www.gpsworld.com/gis
GeoWorld	http://digitalmagazinetechnology.com
GIM International	http://www.gim-international.com/index.php
GIS Café	www.giscafe.com
GIS User	www.gisuser.com
GPS World	www.gpsworld.com
IN The Scan- Laser News	http://LiDARnews.com/
Google Alerts - Keyword searches	www.google.com/alerts

Technical Approach – Field Operations

The data collection for this research was undertaken along Route A in Franklin County, Missouri between the cities of Union and Washington. This area was chosen due to the availability of independent survey control and reference data

Figure 1 Project Route

The data was collected December 16 through December 18, 2009.
Aerial Data was collected December 17, Mobile data was collected December 17 with a test run on December 16 to review the route for any potential collection issues (i.e. active construction, restricted access). The static collection occurred December 17th and December 18, 2009.

Field Survey Operations -Technical Approach

Sanborn in conjunction with EFK Moen established survey control to support the data collection efforts on December 16 and 17th 2009. Sanborn established two base stations as part of the EFK Moen network survey on December 17 to support the mobile, aerial and static LiDAR collection. EFK Moen utilized the MoDOT Global Positioning System (GPS) Virtual Reference Station (VRS) to verify the MoDOT values of the site survey control network were still in compliance with the MoDOT control survey requirements set in March 2009 for aerial and topographic mapping purposes.

EFK Moen re-established the MoDOT GPS reference station values on site, in addition EFK Moen located and tied 4 National Geodetic Survey (NGS) points used in the original survey and tied in vertical control using the same differential level methods as the original March 2009 survey. Reference to values of NGS control stations obtained from the NGS and reported to be on the National Spatial Reference System, NSRS 2007.
The equipment used was TDS Nomad collector software version 1.0.3 and Epoch 35 Antenna, cell freq. 450-470 Mhz.

The common Horizontal NGS Monument points used were FR31 FR 88 FR 25 and FR23, the common Vertical NGS Monument control points used were T334 and J339. The conventional level loop was checked holding the elevations of NGS Monuments T334 and J339, and the Virtual Reference Stations (VRS) values at the observed stations.

EFK Moen Certification

"The horizontal coordinates were established and verified by GPS observations through the use of a cellular device equipped Epoch Model 35 GNSS Rover and TDS Nomad Controller utilizing the Missouri Highways and Transportation Commission Global Navigation Satellite Real Time Network for Continuous Operating Stations. This information was adopted and checked by filed GPS observations to two (2) nad83(nsrs2007) adjusted points. Field observed check stations were as follows; FR-20 with a NGS PID (Permanent Identifier) of AC6167, FR-23 with a PID of AC6170, FR-25 with a NGS PID of AC6234. The site grid azimuth and project grid factor were adopted as calculated by the TDS Nomad survey controller software. The Missouri East Zone NAD83(NSRS2007) state plane grid coordinates for the control points were adopted as calculated by the TDS Nomad survey controller software. To the best of our knowledge, the calculated state plane grid coordinate meet the accuracy standards of the current Missouri minimum standards for property boundary surveys (20 csr 2030-16) as an urban class survey relative to stations FR-20, FR-23, FR-31 and FR-88"[2]
A copy of the full report can be found at Appendix B

[2] EFK Moen LLC Job Lidar Report Appendix B

Aerial LiDAR Data Collection -Technical Approach

Aerial data collection occurred Dec 17, 2009. The aerial data was collected using a Leica ALS50II MPIA (Multiple Pulse In Air) system combined with a Applanix DSS 439 medium format digital camera. The combination of LiDAR and digital imagery enable more accurate filtering and classification of features in the laser datasets

Equipment

The Leica ASL 50 II is a laser based system designed for the acquisition of Topographic and return signal intensity data from airborne platforms. The MPIA system is capable of measuring up to 4 returns collecting at up to 150,000 Hz. The data is computed using range and return signal intensity measurements recorded in flight along with position and attitude derived from airborne GPS and inertial subsystems.[3]

Figure 2 Aerial LiDAR System Leica ALS50-II

The Applanix Digital camera is a 39 mega-pixel (MP) 5412x7216 pixel imaging system.[4] The camera is co-mounted with the LiDAR sensor to allow for capture of simultaneous digital imagery. The camera can collect in natural color or color infrared and create orto-rectified imagery when post processed.

Figure 3 Aerial Digital Camera Appanix DSS 439

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[3] Leica ALS50-II Product Specifications © Leica Geosystems AG Heerbrugg, Switzerland

[4] Applanix DSS 439 Specifications ©2009 Applanix, A Trimble Compnay. All rights reserved. Applanix and the Applanix logo are trademarks of Applanix Corporation registered in the Canadian Patent and Trademark Office and other countries.

Collection

The system was configured to collect approximately 15 points / sq meter – The route was flown twice – primarily in a South to north – then north to south aspect effectively doubling the data density. Two base stations were located in the project area (Point 25a and 113) and were confirmed operating prior to collection. A backup Base Station was established at the airport in the event of a failure of a project base station. All three base stations were Sanborn NovAtel DL-4 Plus high accuracy GPS receivers.

Leica ALS50 II-MPIA	
	High point density
Flight altitude	500 Meters
Repetition rate	139000 Hertz
Scan frequency	88.3 Hertz
Half Scan angle	5 degrees
Scan Full angle	10 degrees
Average Air Speed	100 / 100 Knots
Overlap	N/A
Swath Width	105 meters
Pulse foot print	0.15 meters
Average Point spacing	0.22 meters
Flight Line Spacing	N/A
Projected Hor. Accuracy	7 centimeters
Projected Vert. Accuracy	8 centimeters
Planned Point spacing	15 points per meter

Table 1 Leica Flight Parameters

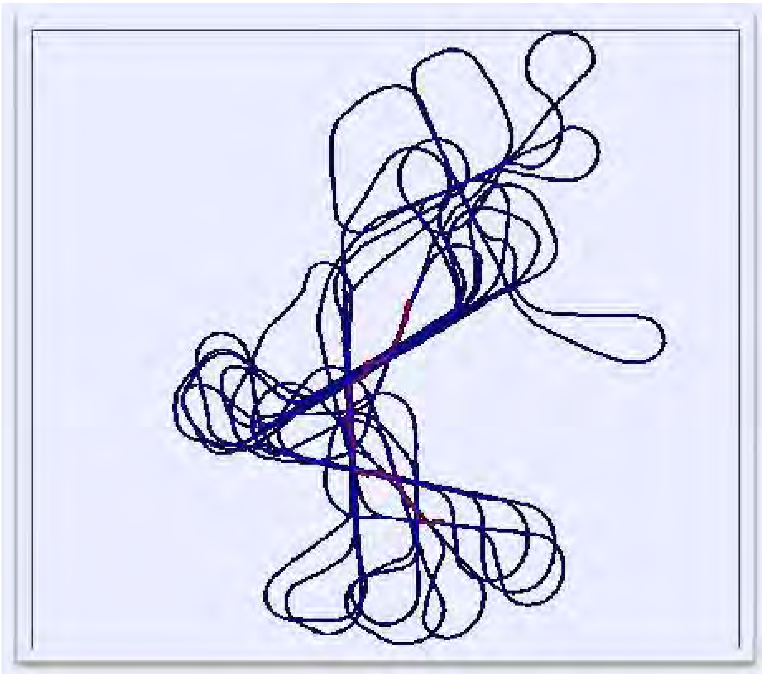


Figure 4 Aerial LiDAR Collection Trajectories (Blue) Route (Red)

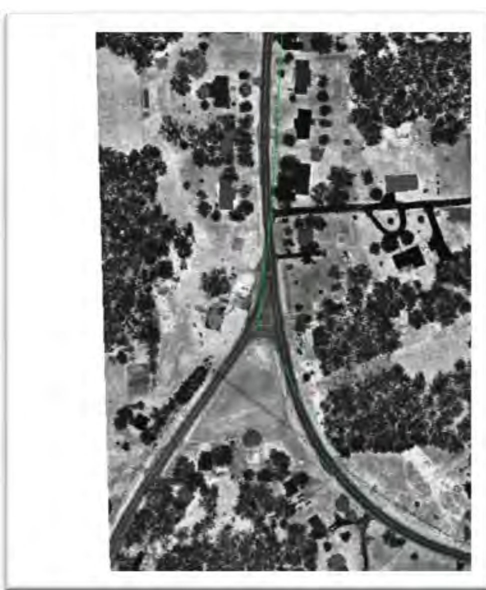


Figure 5 Aerial Laser Intensity Image


Figure 6 Aerial Natural Color Image

Flight Collection

The crew verified equipment functionality, ensured Positional Dilution of Precision PDOP was with allowable tolerances (less than 3.2) and verified flight plans and mission profile prior to departure. The crew set a base station at the airport to create a backup control point in the event of a failure of a station in the project area. (Figure 9)

Flight plans were created using Trackair planning software, this sets the flight altitude, flight line spacing and flight orientation with respect to the project area and laser settings. The pilot follows the TrackAir interface (a graphical interface showing aircraft position to planned flight lines allowing for precise navigation with respect to collection in the project area.

The aerial collection started with a 5 minute static system initialization for GPS and IMU at Washington Regional airport in City of Washington, Missouri. The aerial crew then coordinated with the field team to ensure the project area base stations (point 25a and 113) were collecting prior to system initialization.

The aircraft departed December 17th with flight to collection area approximately 10 minutes. Prior to project collection the crew flew two reference calibration lines (C1-C4 Figure 7&8) at the airport this was also performed after the collect and prior to landing. These lines are flown over the runway in opposite directions at the planned flight parameters for the project area.
The flight plan was designed to collect approximately a 400 foot wide corridor or 200 feet wide from each side of the road centerline.

LEICA FLIGHT LOG	PROJECT: 332010181 MDOT	AREA FLOWN: MDOT
	DATE(YYMMDD): 091217	JULIAN DATE: 351a

SENSOR NAME: SN40				
MEASURED ANT HEIGHT: [REC1] 2.065 [REC2]	GROUND WEATHER CONDITIONS		GROUND	ALTITUDE
FLIGHT VENDOR: Sanborn	TEMPERATURE:			
AIRCRAFT ID/PILOT: N. Freeman	DEWPOINT:			
AIRPORT: KFYG	PRESSURE (inHG):			
LIDAR OPERATOR: Jill Wrenn	WIND DIRECTION			
HOBBS: 2.9	WIND SPEED			
SENSOR USE: 2.2	CLOUD CONDITIONS			
OPTICS CLEAN: YES [X] NO [ ]	SURFACE CONDITIONS (WET/DRY/SNOW)			

FOV: 25	PULSE (Hz): 139000	SCAN (Hz): 50	LASER %: 12	MULTI [ ] SINGLE [ ]
HARD DRIVE #: 1	POS CARD #: A			

OFFICE USE	LINE #	MISSION ID	HEADING (N/S/E/W)	START TIME	END TIME	RANGE (M)	RETURNS (%)	PDOP	LINE COMMENTS
	Test	165421	—	1654	1655	—	—	—	
	C1	171258	301	1712	1714	600	100	1.5	=
	C2	171852	65	1718	1719	600	100	1.5	⊥
	13	172726	201	1727	1729	600	100	1.7	
	13	173258	21	1732	1734	600	100	1.7	
	12	173610	239	1736	1738	600	100	1.8	
	12	174053	56	1740	1742	600	100	1.8	
	11	174624	239	1746	1748	600	100	1.8	
	11	175248	59	1752	1755	600	100	1.8	
	10	175826	239	1758	1800	600	100	1.9	
	10	180414	59	1804	1806	600	100	1.9	
	9	181003	239	1810	1812	600	100	2.3	

NOTES: RUNWAY 3X

ADDITIONAL NOTES ON REVERSE: [ ]

PAGE 1 OF 2

ver. 1.0

Figure 7 Flight Log Page 1

LEICA FLIGHT LOG	PROJECT: 332010181 MDOT	AREA FLOWN: MDOT
	DATE(YYMMDD): 091217	JULIAN DATE: 351a

OFFICE USE	LINE #	MISSION ID	HEADING (N/S/E/W)	START TIME	END TIME	RANGE (M)	RETURNS (%)	PDOP	LINE COMMENTS
	9	181553	60	1815	1817	600	100	1.7	
	8	182322	176	1823	1825	600	100	2.1	
	8	182920	356	1829	1831	600	100	2.1	
	7	183628	176	1836	1839	600	100	1.6	
	7	184237	356	1842	1844	600	100	1.6	
	6	184942	101	1849	1851	600	100	1.6	
	6	185413	281	1854	1855	600	100	1.7	
	5	190014	101	1900	1902	600	100	1.6	
	5	190534	281	1905	1907	600	100	1.6	
	4	190941	161	1909	1911	600	100	2.5	
	4	191447	341	1914	1916	600	100	2.6	
	3	191939	138	1919	1921	600	100	2.6	
	3	19240	318	1924	1924	600	100	2.5	
	2	192726	178	1927	1929	600	100	2.5	
	2	193130	358	1931	1933	600	100	2.3	
	1	193519	96	1935	1936	600	100	2.3	
	1	193920	276	1939	1940	600	100	2.2	
	C3	194440	68	1944	1945	600	100	2.0	⊥
	C4	194818	244	1948	1949	600	100	1.9	⊥

NOTES: RUNWAY 3X

ADDITIONAL NOTES ON REVERSE: [ ]

PAGE 2 OF 2

Figure 8 Flight Log Page 2

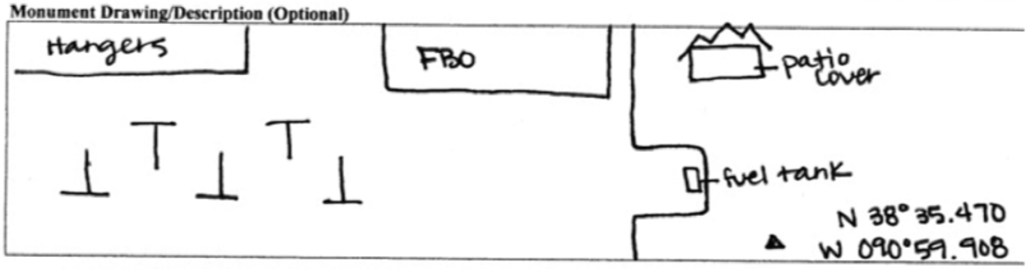
LiDAR BASESTATION LOG V1 06/06/07 SANBORN

Date (mm/dd/yyyy): 12/17/2009	LiDAR Mission(s): 351a
Project: 332010181 MDOT	Observer: Josh & Jill

Antenna Formulas

4000SSi / 4000SSE Compact L1/L2	Bottom of notch in antenna flange $= 0.0069 + (h^2 - (0.0915)^2)^{1/2}$
Trimble 5700 Zephyr (small)	Top of notch in antenna flange $= 0.0073 + (h^2 - (0.0937)^2)^{1/2}$
Trimble 5700 Zephyr Geodetic (large)	Bottom of notch in antenna flange $= 0.00891 + (h^2 - (0.16981)^2)^{1/2}$
Novatel DL	Top edge of tape notch $= 0.015 + (h^2 - (0.96)^2)^{1/2}$
Novatel DL4	Top edge of tape notch $= 0.025 + (h^2 - (0.1)^2)^{1/2}$

Monument Drawing/Description (Optional)



LiDAR BASESTATION ANTENNA INFORMATION

Reciever Serial #: 0019 **File Name:** 00193510

Code:	Description: Set 6" spike	Session: 0
Stamping:	@ Washington Regional	Start (UTC): 1530
PID	Airport (KFYG)	End (UTC): 2019

Measurements

_______ " _______ m Uncorrected _______ meters → True Vertical _______ meters Fixed Height Tripod = 2.0 meters

_______ feet → _______ m → (mean)

Reciever Serial #: **File Name:**

Code:	Description:	Session:
Stamping:		Start (UTC):
PID		End (UTC):

Measurements

_______ " _______ m Uncorrected _______ meters → True Vertical _______ meters Fixed Height Tripod = _______ meters

_______ feet → _______ m → (mean)

Reciever Serial #: **File Name:**

Code:	Description:	Session:
Stamping:		Start (UTC):
PID		End (UTC):

Measurements

_______ " _______ m Uncorrected _______ meters → True Vertical _______ meters Fixed Height Tripod = _______ meters

_______ feet → _______ m → (mean)

Code: Numbering Convention: begin with 501, 701, 801, 901

1- 499: paneled points	800 series: NGS vertical only
500 series: Sanborn set for base	900 series: NGS horiz. and vertical
700 series: NGS Horizontal only	1' = 0.3048 m; 1" = 0.0254 m

Description Examples: 12" spike, 6" spike, rebar, pk nail, mag nail, Disc in concrete, rod in sleeve, Disc in seawall, etc. **AND INCLUDE** Airport name if monument at airport

Figure 9 Airport Base Station (Used for System Verification)

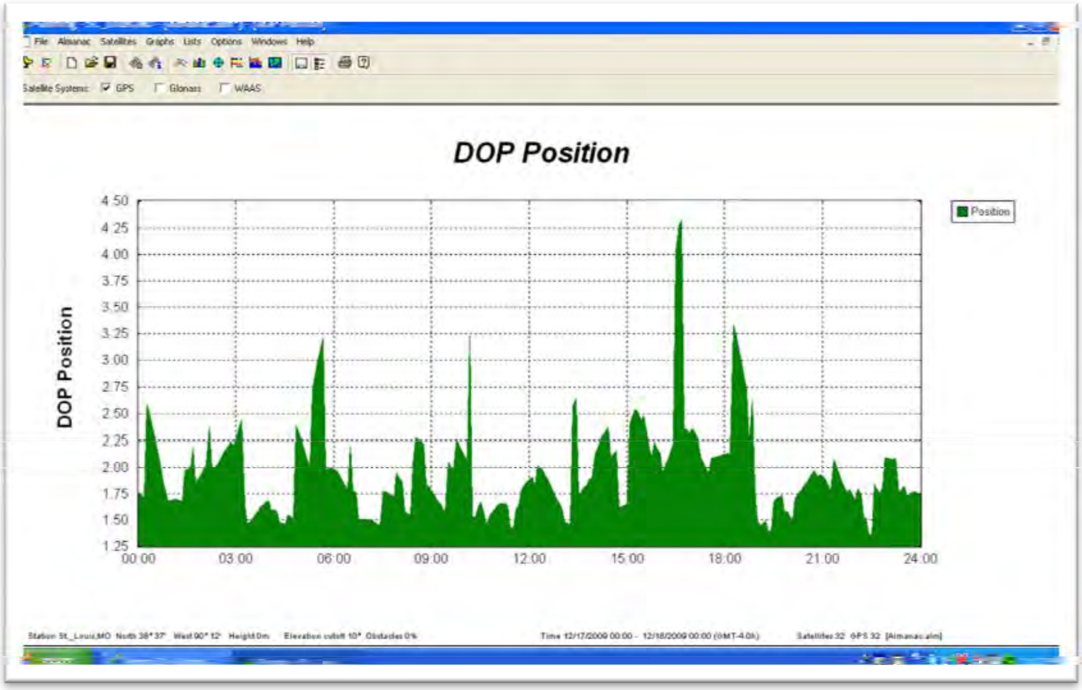


Figure 10 PDOP Planning

Field QC

During flight the system "health" is monitored to ensure all subsystems are operating in normal ranges via the operator console. PDOP is monitored and recorded on a per flight line basis to identify any PDOP spikes that would require a re-flight; re-flights are required for PDOP above 3.2. At the end of the mission the data is copied to a transfer drive and shipped to the office. The operator will verify data coverage in the field using initial processed GPS positioning to verify aircraft track.

Post Processing Procedure

Using the EFK Moen survey control and base station information for calibration of the aerial data collection, the data was then processed in the office using Leica's ALS post processing SW and Applanix POSPAC MMS for post processing of the GPS and Inertial Measurement Unit IMU data.

The output .las files were loaded into a GeoCue project environment for data processing and management.

"The .las file format is a public file format for the interchange of LIDAR data between vendors and customers. This binary file format is an alternative to proprietary systems or a generic ASCII file interchange system..."[5]

GeoCue is a data management software system that facilitates data management, production processing and final product generation for LiDAR data sets. The GeoCUE LiDAR Cue PAC was used to facilitate the organization and the multi-user processing for filtering and editing. Due to the size of the files, greater than 50 Million points the aerial data sets were tiled to facilitate processing and editing. The aerial LiDAR mission was tiled into 34 tiles 1500ft x 1500 ft with any single file not exceeding 8 million points, this took approximately 8 hrs to setup and 20 hours to process.

The data sets were tiled to optimize the point density along the route. The width of the route was set at 300 feet – 150 feet either side of the centerline based on supplied feature data. The resulting average tile is approximately 12 Million points. The data sets were then filtered to extract bare earth for use in surface modeling using Terrasolid's Terrascan product. Custom filter parameters were generated and the point cloud was automatically filtered to classify bare earth points. Each tile was then manually reviewed and edited using Terrasolid's Terramodeler product that allows interactive editing of the data.

The filtering of .las data does not change the point count in the files, as part of the classification the points are "attributed" with a classification according to ASPRS .las specification, the default classes are class 2 bare earth, class 0 or 1 created or unclassified, class 3,4,5 vegetation, class 6 buildings.

The datasets were then inspected for accuracy in the bare earth filtering, and the bare earth classified tiles were output in ASCII format.

[5] American Society For Photogrammetry and Remote Sensing
http://www.asprs.org/society/committees/lidar/lidar_format.html

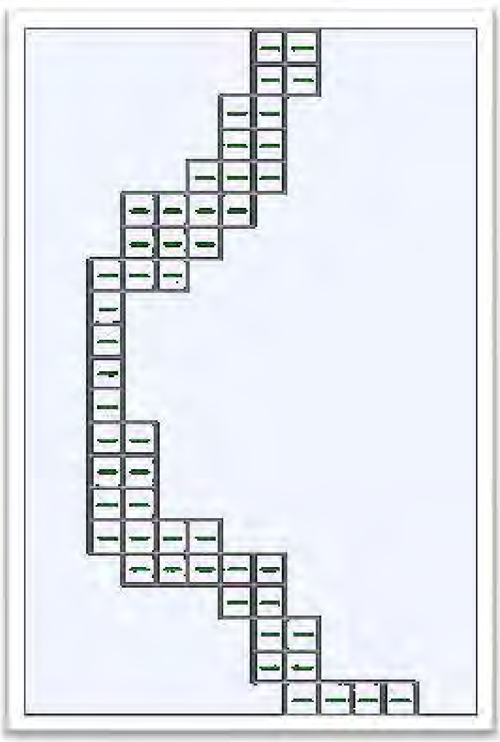


Figure 11 Aerial Tile Scheme

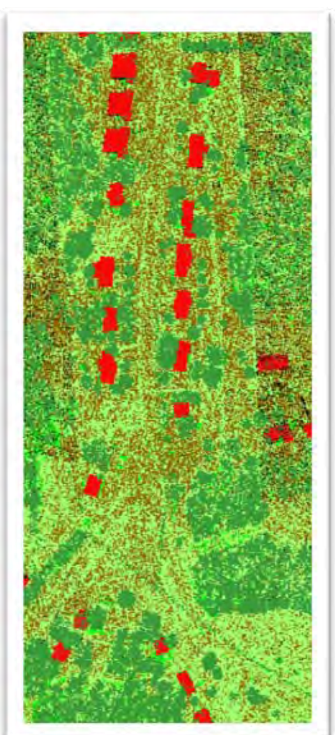


Figure 12 Classified Laser - (Top View) Ground, Buildings, Vegetation

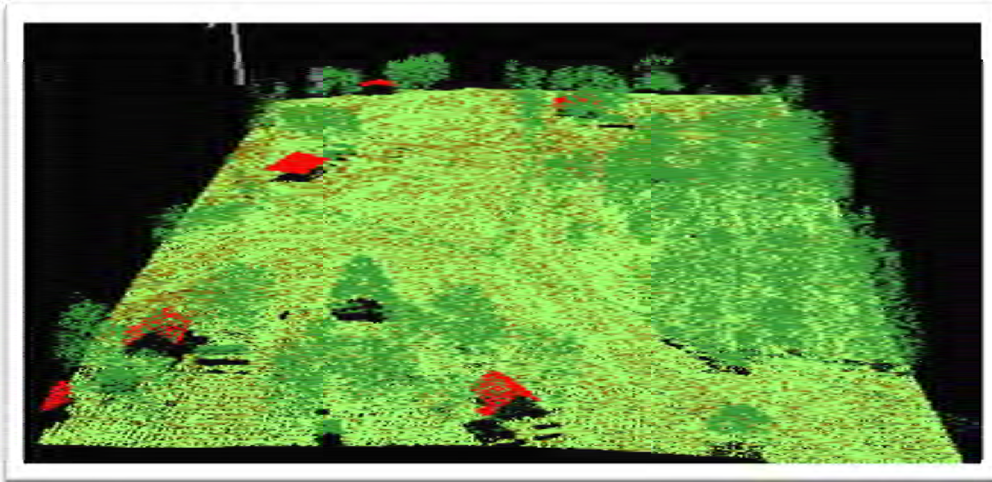


Figure 13 Classified Laser (Front View) Ground, Buildings, Vegetation

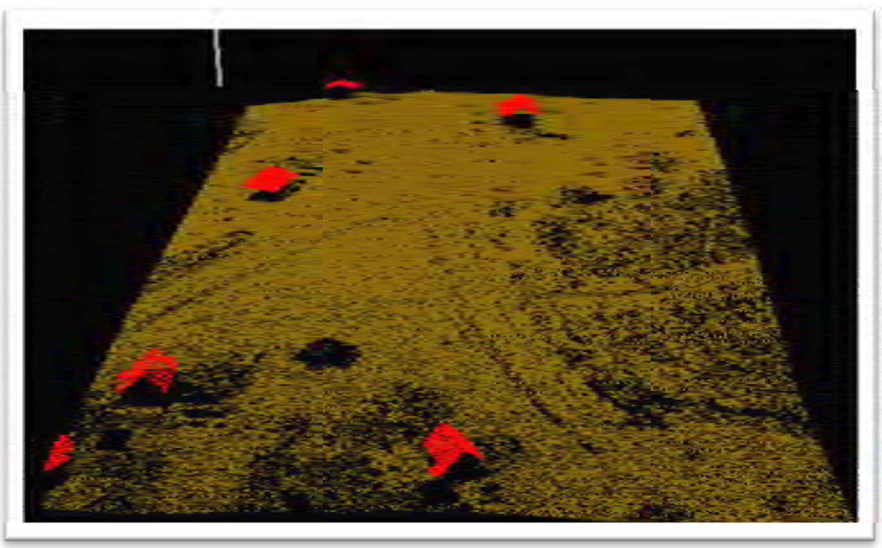


Figure 14 Bare Earth and Buildings

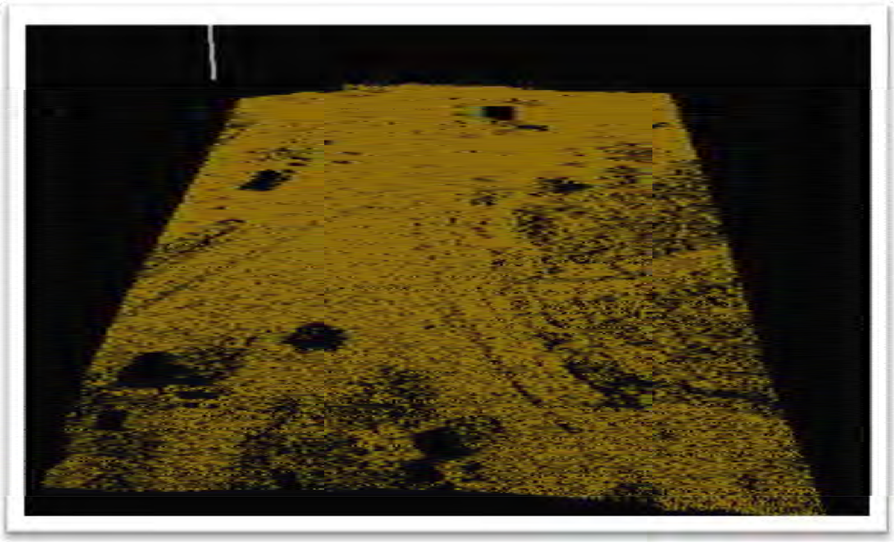


Figure 15 Bare Earth

The total project point count by classification after automated and manual processing is outlined in Table 2 (below).

Class	Points
Default	39,871
Ground	30,815,366
Low Vegetation	57,778,875
Medium Vegetation	2,680,066
High Vegetation	18,064,128
Buildings	3,105,888
Low Points	5,266
Total	112,489,460

Table 2 Aerial Point Count

Mobile LiDAR Data Collection -Technical Approach

The mobile data collection occurred first on Dec 16 2009 as a test drive and system validation for the collection. The system was tested for GPS/IMU solution, and data capture ensuring that during the travel to the site no system operational components were affected. On Dec17, 2009 base stations were established under the guidance of EFK Moen to support the mobile and aerial collections. These stations are identified as 25a and 113. Both stations were collecting at 0.5 seconds for the duration of both aerial and mobile collection on December 17, 2009.

Equipment

The system deployed was an Optech Lynx, consisting of Dual 200Khz Lasers, 2 GPS antennas and a Inertial Measurement Unit (IMU). The system was configured to collect at the full 200 Khz per laser head effectively collecting 400,000 points/sec. One key aspect of the test drive was to identify areas where logical breaks for data collection could occur. This aspect is critical for post mission processing. By collecting in short segments (approx <0.5miles) the risk that a period of poor GPS reception will adversely affect the post processing is minimized. In addition short segments can be processed through the calibration software whereas long missions (1 mile >) can cause errors in software and post field additional data processing is required.

Figure 16 Mobile Mapping System

Collection

The route (Figure 1) was driven in both directions to ensure maximum coverage and reducing the potential of laser "shadows" obscuring features of interest. Mission planning for collection is based on a number of project specific variables including traffic density and patterns, single, dual or multi-lane highways and obstructions, near road obstructions, walls, vegetation etc. Missions are designed to optimize data collections and minimize shadow areas.

The PDOP was checked to ensure it was below 3.2 (using the same PDOP Planning data as the aerial to ensure both collects would fall within the same PDOP windows in Figure 10)

The data was collected in 15 segments (missions) – the system health was monitored using the laptop controller that provides a "health" reading on the sensor and the collection allowing for real time monitoring of GPS solution and data collection from the sensors. By breaking the collection into missions allows for smaller raw data blocks that can be processed through the Optech Lynx post processing software

Post Processing

The GPS and IMU data was post processed using Applanix's POSPAC Land which processes the GPS and IMU data into trajectories. The results of POSPAC Land was used to compute the positioning of the .las point cloud processed using Optech's DASHMAP SW for converting the "raw" laser data to .las files.

The GPS output is reviewed and verified, number of satellites, PDOP and final Smoothed Best Estimated Trajectory (SBET) Day 351 B Dec 17th 2nd mission (Figures 17-20)

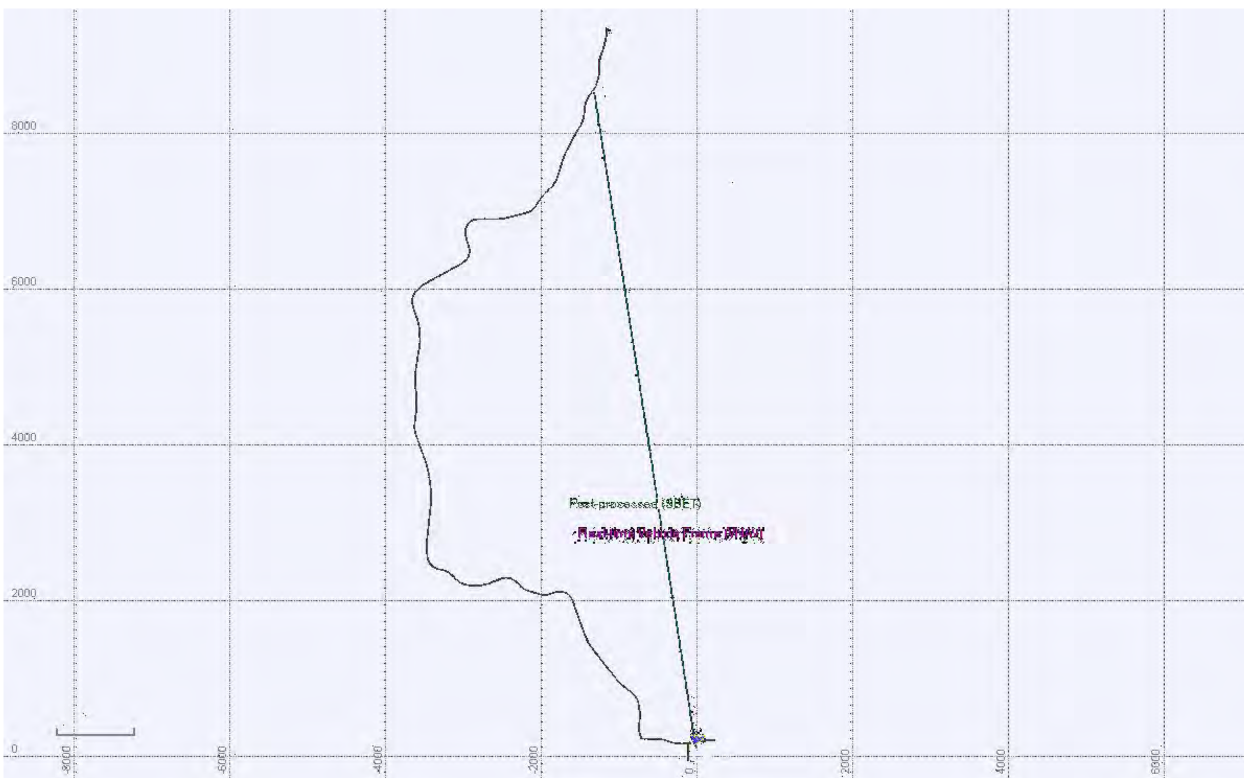


Figure 17 GPS Track

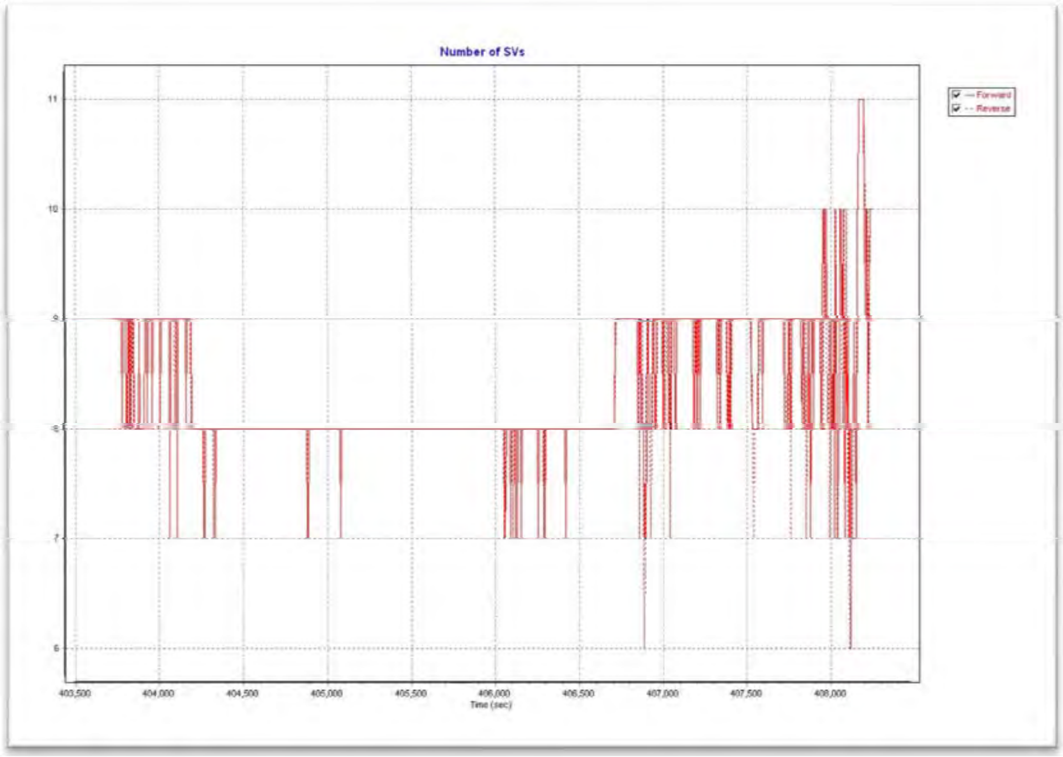


Figure 18 Number of Satellites

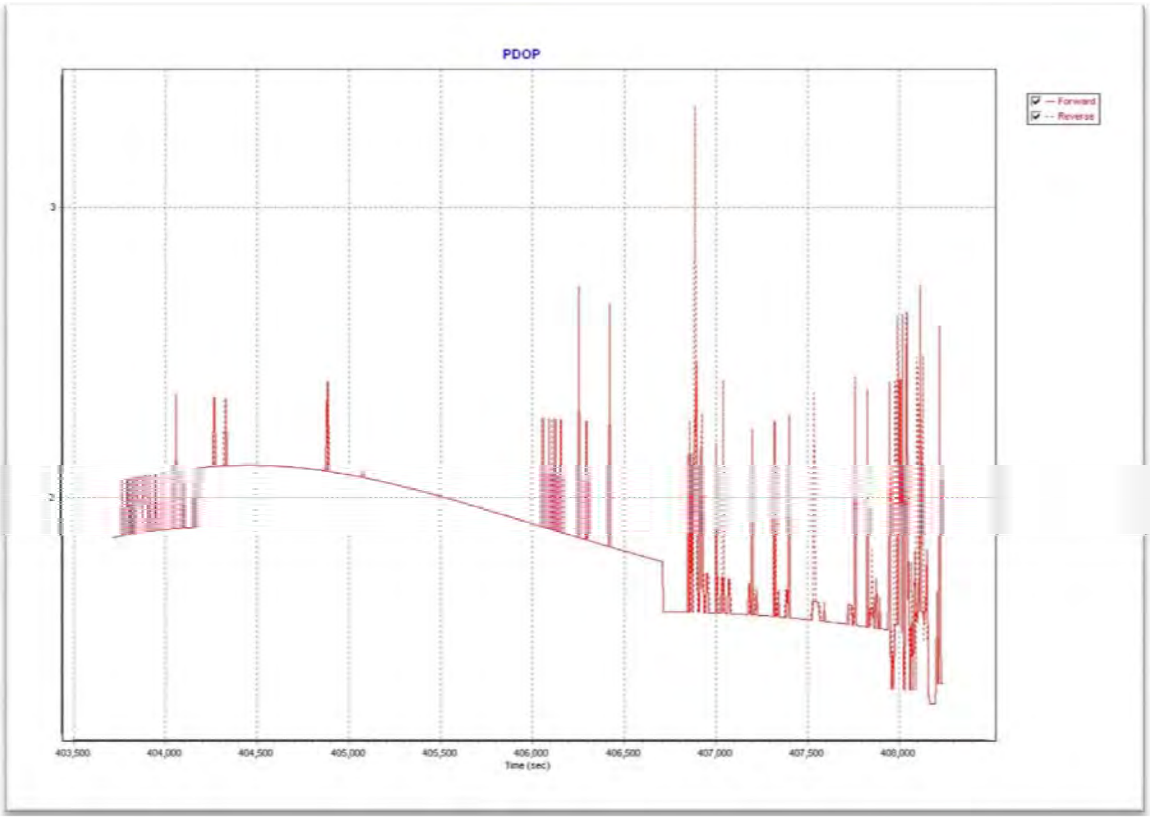


Figure 19 Chart of PDOP

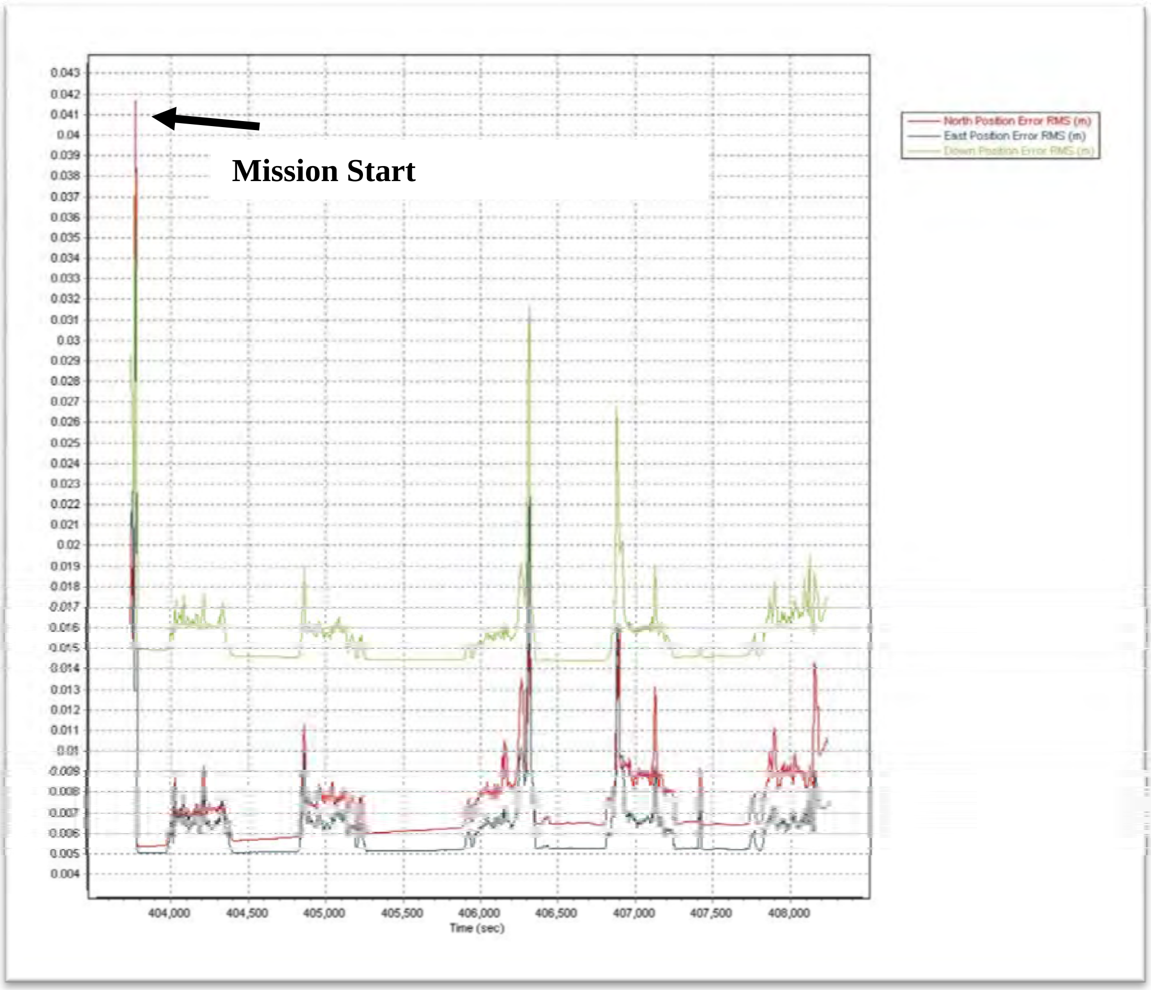


Figure 20 SBET Review

SBET results x & y for B mission segment nominal 1cm or less and z 1.6 cm

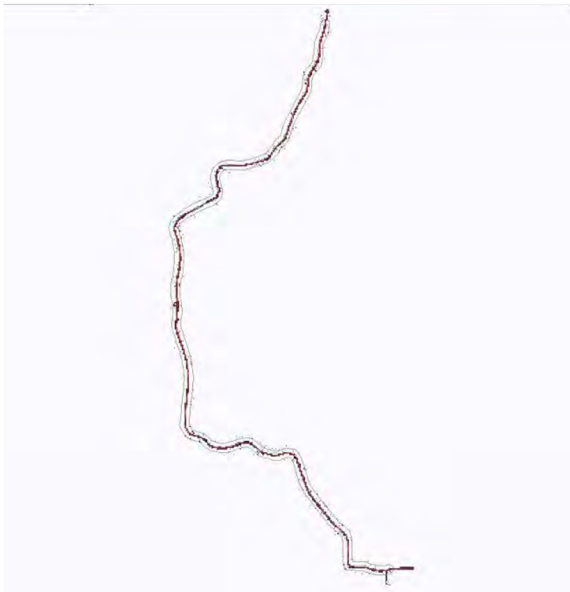


Figure 21 Mobile Trajectories

Combined trajectories for 3 mission segments from collection (Fig 21)

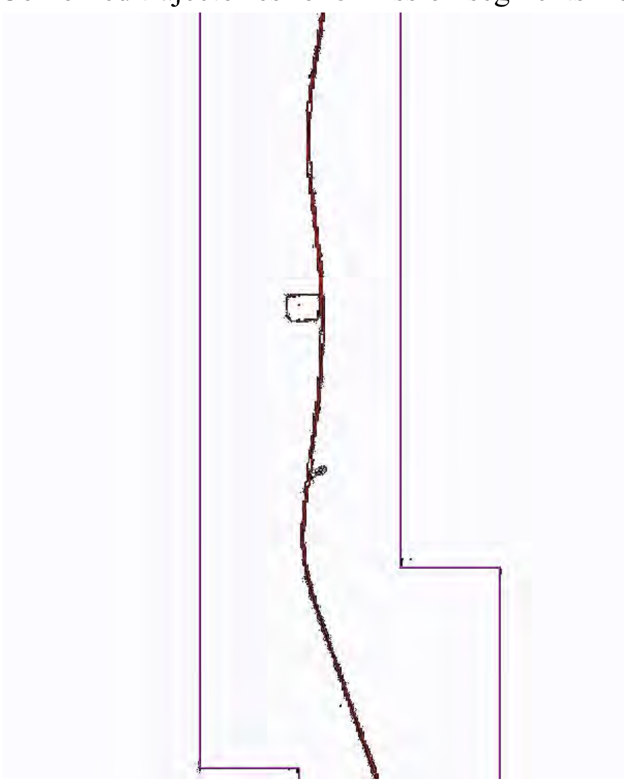


Figure 22 Mobile Trajectory

Figure 22 shows detail of collection position and trajectory data (track of the vehicle) mission B

Post Processing Procedures

The mobile data "missions" were then loaded into GEOCUE. A new module GEO CUE Lynx MMS Cue Pac was required in order to process and manipulate the approximately greater than 0.5 Billion points from the mobile system. There were significant issues in dealing with a data set of this size, initial processing and tiling attempts failed due to large file data sizes. Also in a mobile mission there are many "strips" for both sensors and that the software was treating each scan as an "aerial" mission which uses a unique mission and strip id. This required a workaround and manual renaming of the strips to load the sensor and strip segments. A strip is defined as a unique sensor, mission and strip (as in aerial) but in mobile there are 2 sensors, 1 mission and multiple "strips" (from the two sensors).

A scheduled update to the software version 6.1 in March 30 2010 allowed the entire mobile data set to be loaded into the project for subsequent tiling and processing as a single project as well as improving the ability to load SBET and GPS track for managing the individual "mission" segments.

This required a smaller tile scheme to manage the datasets (Figure 23) for processing in TerraScan; this resulted in the largest tiles being approximately 15 million points. The number of total tiles created were 226 tiles, 500ft x 500ft. The filtering and editing was performed using Terrasolid's TerraScan and Terramodeler creating a bare earth surface from the point cloud (Figure 24 & 25).

Additional challenges with this aspect of the laser processing resulted from the fact that most of the processes, filtering, classifying and manual editing tools and methods have been developed over the last decade focusing on aerial data. The density of the mobile datasets significantly reduced the effectiveness of the filters and processes. This required additional development of modified filtering parameters and creating an iterative filter-check-modify parameters filter and manual edit process.

Each tile is loaded into TerraModeler to review the accuracy of the automated filters; points were manually classified to bare earth in areas where the filter misclassified the points. Manual review and edit was required more extensively for the mobile data due to difficulties in the automated filters in correctly defining low bushes and ground clutter.

The resulting point class count is as follows: Mobile Data (not including noise points)

Class	Points
Default	12,930,697
Ground	88,843,333
Low Vegetation	429,024,011
Medium Vegetation	24,694,914
High Vegetation	101,940,979
Buildings	1,018,456
Low Points	14,308
Total	658,466,698

Table 3 Mobile Point Count

Figure 23 Mobile Tile Scheme

Smaller footprint tile scheme to manage the high density of point cloud data

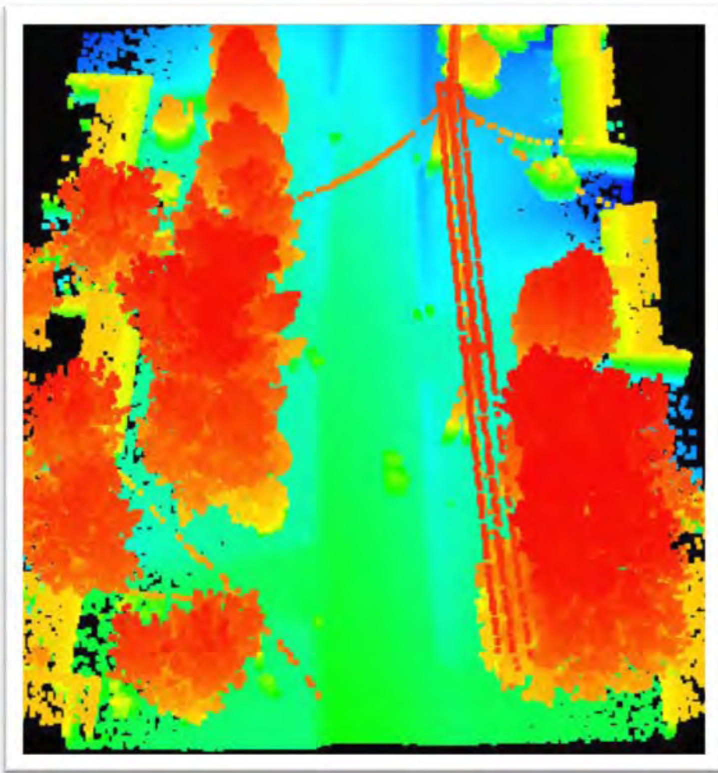


Figure 24 Mobile Data - All Points

High density mobile data "paints" the earth with points. Resulting point density is approx 1cm point spacing on the ground

Figure 25 Mobile Bare Earth points

Resulting bare earth surface after filtering approximately 1cm data density on the road surface in the bare earth classification

Figure 26 Aerial Sample

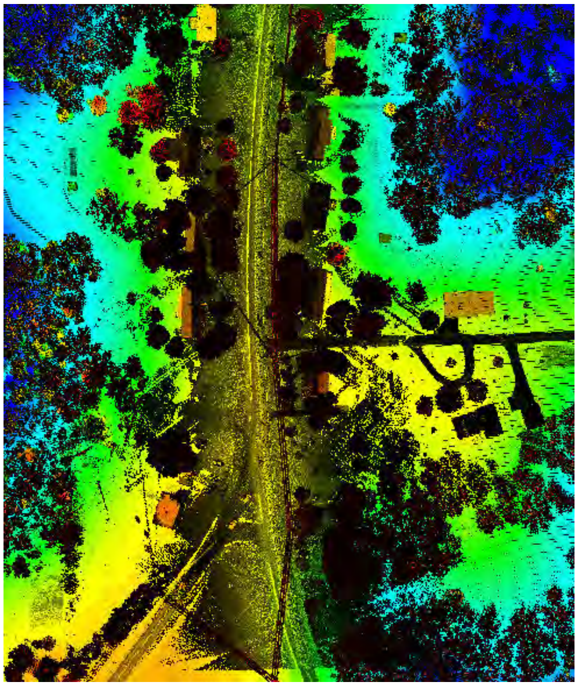


Figure 27 Lidar Colored by Elevation Range

A relative elevation "map" with dark blue being lowest points in the view up through green, yellow, to red; the highest points. Effective for quick visualization of the data sets

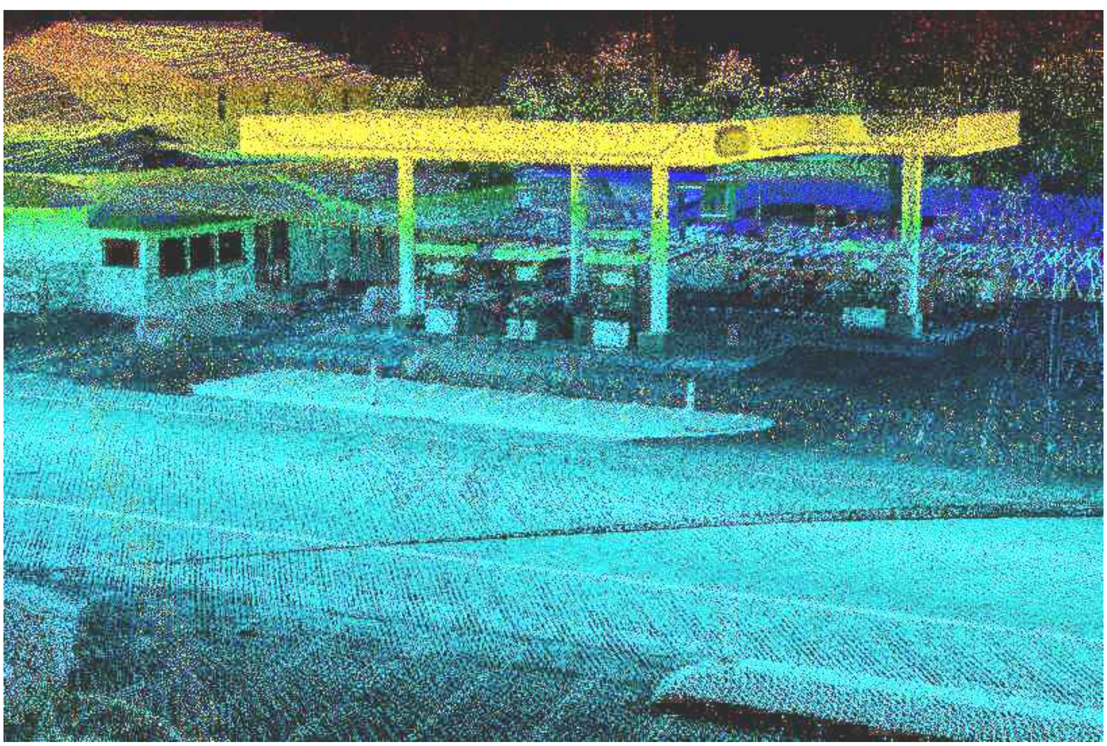


Figure 28 Combined Aerial and Lidar Data

Aerial and mobile data combined into single las for viewing purposes

Final Processing Of Aerial and Mobile Data

The filtered bare earth data sets generated into 3 different ASCII surface types. One surface containing all points resulting in a surface of over 88 million points, one bare earth surface using a intelligent thinning to retain a point approximately every 3 feet resulting in a 4 million point surface, and a third bare earth surface using intelligent thinning to retain a point every 1foot approximately resulting in a surface of > 20 million points. These surfaces are based on interpolation but retaining original point measurements based at the intervals above. The smaller point count surfaces are able to be more readily used in Microstation Geopak for surface generation to support surface analysis.

Static LiDAR Data Collection -Technical Approach

Sanborn collected a target sample area using both a Trimble GSX Advanced Terrestrial Scanner and the Optech ILRIS on Dec. 17 and Dec. 18 respectively at approximately 1cm relative point spacing to match the data density of the mobile scanner. The resulting datasets were processed to LAS point cloud using Trimble's "RealWorks" and Optech's point cloud transformation workflow. The resulting data sets were calibrated using collected survey targets and feature matching using TerraSolids TerraMatch software to tie the scan into the mobile data. The resultant .las file sets were examined for additional information detail and content with respect to the mobile dataset. This data did not hold significant additional informational content from the mobile collect and was incorporated as a representative sample of this technology.

Figure 29 Optech ILRIS 3D Laser Scanner

The Optech scanner is a survey grade laser imaging device, capable of collecting laser point cloud data from 3m – 1500m.

Figure 30 Terrestrial Scan Location

Figure 31 Trimble GX Advanced Terrestrial Scanner

The Trimble GX Advanced scanner is a survey grade laser imaging device, capable of collecting laser point cloud data from 0m – 350m

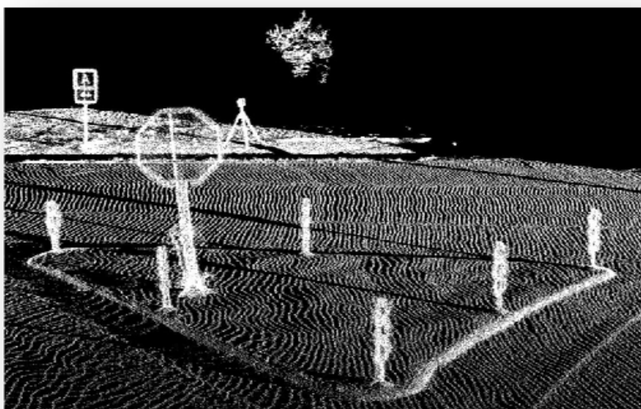


Figure 32 Static LiDAR Intersection Route A and Highway BB

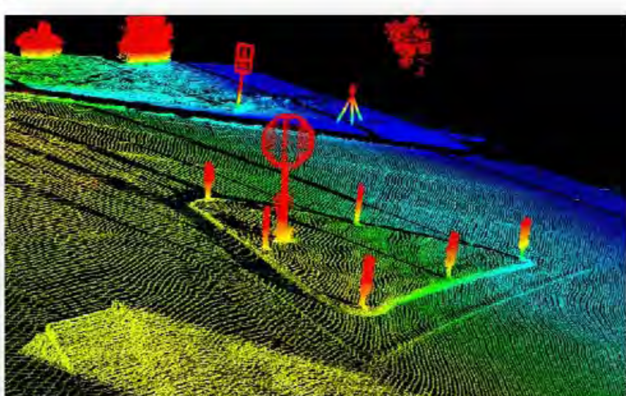


Figure 33 Static LiDAR Intersection Route A and Highway BB Colored by Elevation

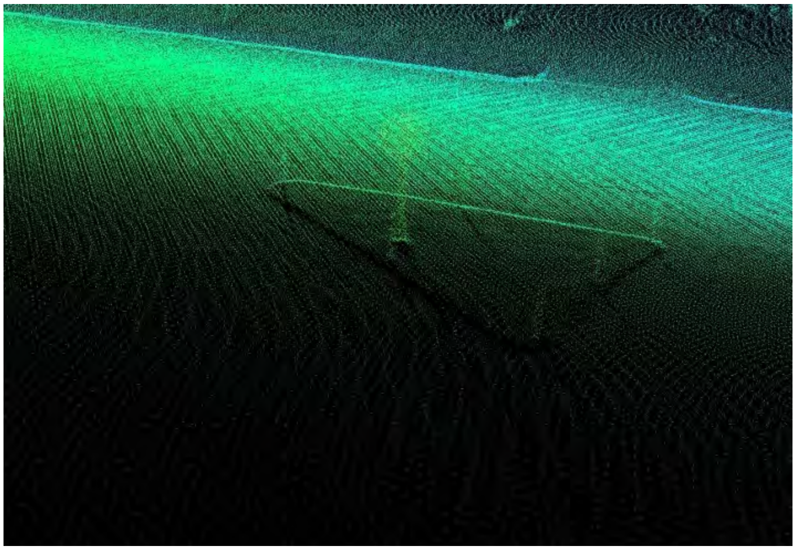


Figure 34 Mobile LiDAR Intersection Route A and Highway BB

Feature Extraction – Technical Approach

After initial calibration and tiling, the feature extraction process that was initially used was to export the TerraScan .las point cloud files into a Microstation dgn file and direct digitizing in the point cloud. This proved to be extremely difficult and inefficient due to limitations in the ability to load and view the point cloud as well as “snap “ to and select the correct points to digitize and extract the features. This approach was abandoned due to lack of tools and robust software to perform this task. As stereo collection using LiDAR- Grammetry has been utilized for breakline and feature extraction on past LiDAR projects it was determined that all features would be extracted using this method.

Synthetic “black & white” Stereo Imagery was generated from both the mobile data and aerial datasets using GEOCUE LiDAR1 Cue PAC for use in feature mapping in 3D stereo environment. The stereo imagery was created using all point classes to create 3D datasets comprising all the required features. The data was created and loaded in Intergraph’s ISSD and ISFC stereo mapping tools. The stereo models were based on the tiles created for the LiDAR data. Aerial LiDAR “imagery” was created at a 6 inch synthetic resolution; the mobile data was created at a synthetic 4 inch resolution. The data was digitized into a single dgn file. The following features were captured: buildings, drain lines, gravel road, signs, paved road (also driveways), power poles, utility poles, impounded or standing water, light poles, roadway breaklines, trees and shrubs. The files were checked by a senior technician prior to release.

One significant factor was the inability to “view” and capture data from a “perspective other than “look down” traditional stereo approach. Given the information content visible in the mobile data sets in the point cloud; the stereo tools available limit the ability to capture this additional information. Additional tools for viewing and manipulation of the point cloud include Applied Imagery’s Terrain Modeler software that allows 3D viewing of the point cloud; however it does not support any feature extraction.

Newly released tools by Certainty3D called TopoDOT (June 2010) will support the unstructured point clouds for the mobile mapping systems and hold potential for direct feature mapping in a 3D environment into Microstation native file format.

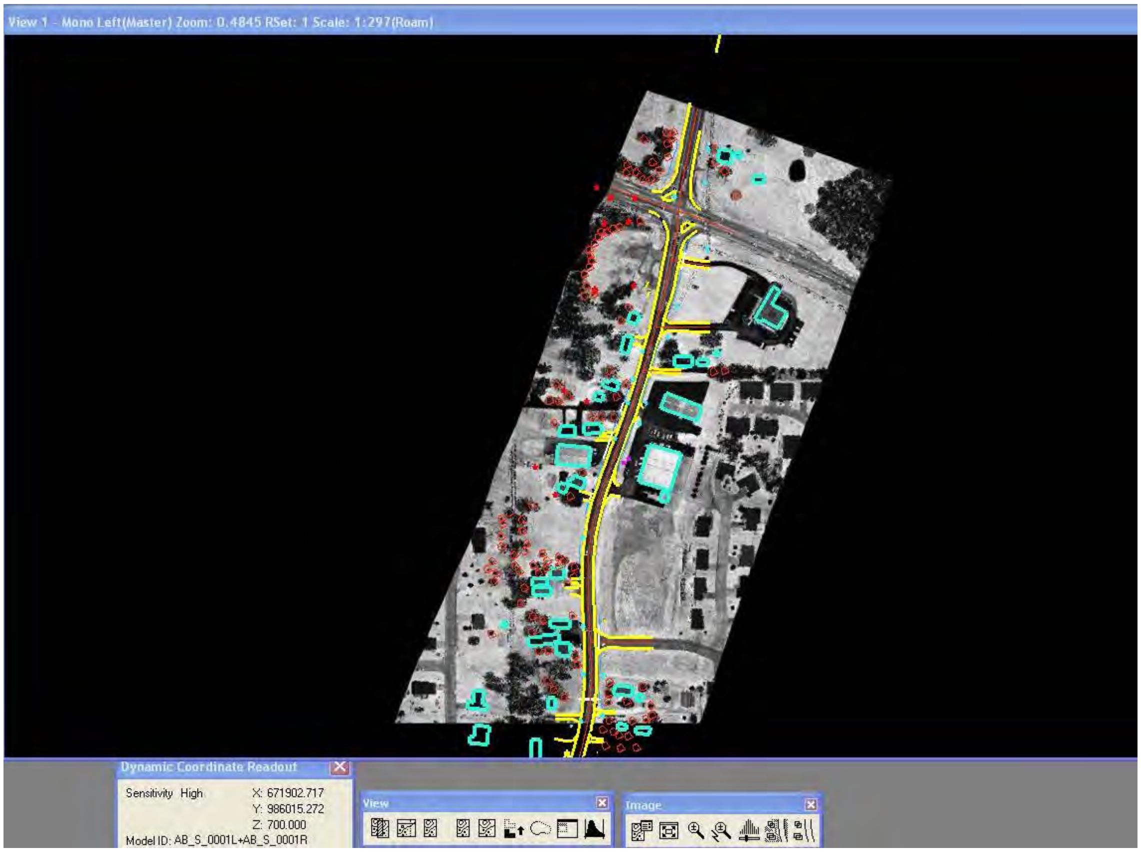


Figure 35 Stereo Intensity Image

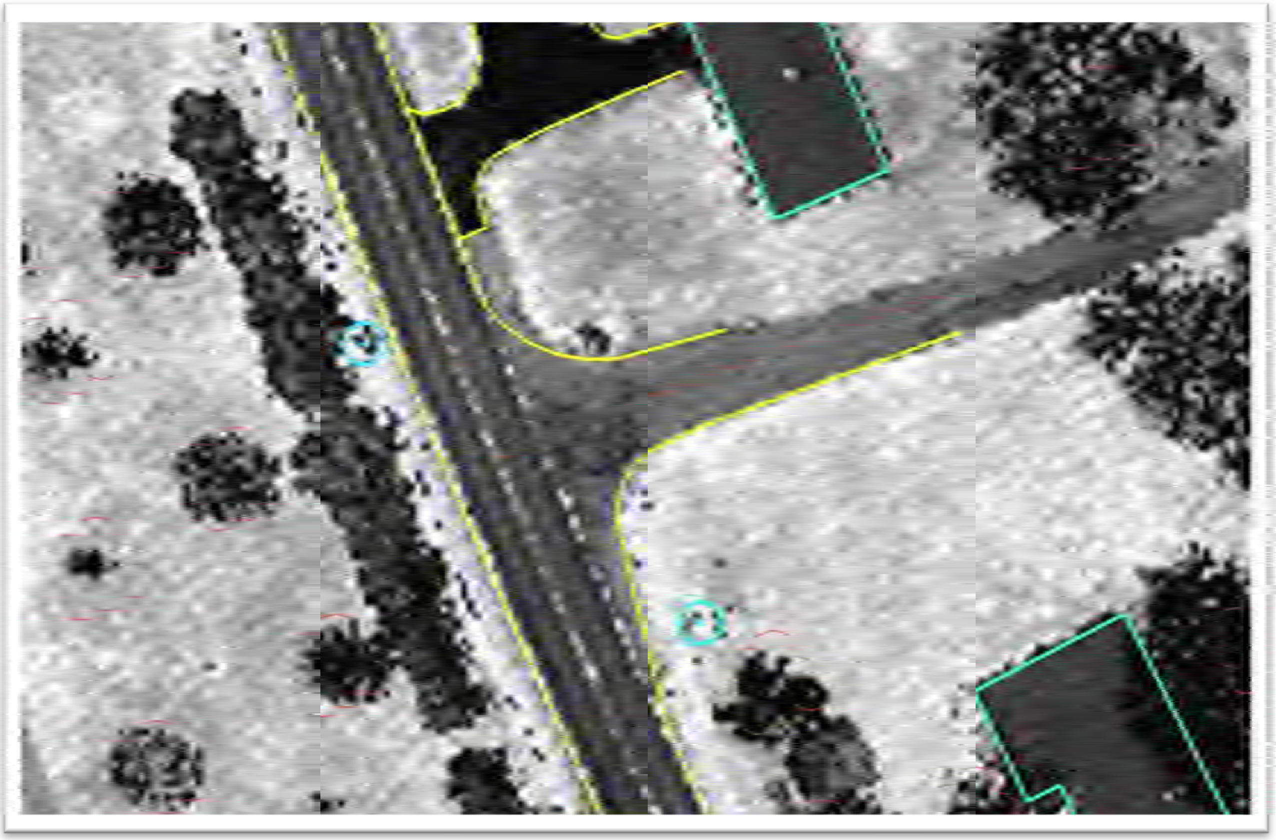


Figure 36 Mobile Stereo Image

Quality Control Plan

The quality control plan was developed to verify each step of the data collection and data processing steps. HDR acted as independent Quality control on data accuracy, formats and deliverables and provide input for the final report

Apart from basic procedures such as measuring instrument heights in meters and feet and comparing the results before leaving the field, Sanborn's primary LiDAR quality control procedures include processing the airborne or mobile GPS data in both forward and reverse temporal directions, and processing with respect to at least two GPS base stations.

Sanborn performs rigorous post-processing of the GPS data, yielding more accurate and reliable results than the straightforward use of the real time internal navigation system (INS) output. In addition static initializations on the ground are made before and after each airborne mission.

Pre-mission and post-mission calibration passes are made for every mission over an independently surveyed data validation test site, which will be situated near Sanborn's base of operations.

The complete series of quality control tests done in the field also include complete processing of the IMU data with Applanix POSpac software to check the quality of the IMU data. Post processing of all LiDAR data flight strips is done to verify quality and coverage of the LiDAR data using the Leica ALS post processor and Trimble's TerraModel Software. The GPS control Network and Check points were verified using Trimble's TGO, GPsurvey, and GeoLAB Software.

Prior to flying the project area we collected two passes perpendicular to the runway in opposing directions (C1 & C2) in the flight logs. At the end of every mission collection, two additional passes over the runway were flown (C3 & C4). One pass was parallel to the runway to detect edge of scan differences in relationship to the runway and other calibration lines. The final line was flown perpendicular to the runway to check the swath repeatability from the beginning to the end of the flight.

The mobile data GPS was monitored directly by the system providing realtime solution analysis and indicating areas of weak or PDOP. This is the reason that the mobile system collection is broken into segments, to reduce the risk of long periods of poor GPS.
Field Steps: Check QC: verify swath, and scans for the mobile, drive and flight data, ground reference data, verify GPS and IMU quality.

Office Steps: Extract POS data, perform the processing of Survey network and network adjustment and verify results. The next step is the processing of the GPS data and to validate the GPS data. Following that the runway calibration data is processed and validated. Following that the runway strips are processed (C1-C4) and the system calibration is validated.

Once calibrated and verified all laser data is converted from raw to LAS using the project calibration values and out- put as strips. Following calibration and output the project is set-up in GEOCUE, creating the tiling structure and project extents. Both the mobile and aerial trajectories and LAS data files are then imported into the project and coverage is verified. Following these steps are the filtering and manual editing of the LAS files using Terrasolids, Terrascan and Terramodeler software.

The filter process requires adjustments to the algorithms based on terrain type. Different types of terrain, vegetations, and urban areas require different algorithms. Based on the complexity of the project area, different values will be applied based on the terrain slope, proximity of adjacent points and the structure of these points. Adapting the filtering parameters is an iterative process due to data size, terrain and localized conditions (i.e. vegetation density, building density).

Following filtering a manual QC for any anomalies and data issues is performed on a tile by tile basis. Manually editing and QC of every tile is performed. This step ensures there are no tile boundary artifacts or voids between DEM tiles and no avoidable miss-classification of returns as well as checks for correct classification of identifiable artifact, vegetation, building, and outlier removal as required. Independent or 3rd party control points are then run against the bare earth surface and the results are reviewed for any anomalies or issues.

There is then the Final QC check, including independent accuracy assessment and delivery performed by HDR an independent party for this project from the data producer.

Lidar Data Import to Design Software Technical Approach–GeoPAK TIN

The initial delivery of the .las files that contained the aerial and mobile data was completed on May 21, 2010. A total of 14 aerial files and 226 mobile files comprised the complete data set. HDR was tasked with converting this information into a format that can be utilized within the standard Missouri Department of Transportation (MoDOT) design and drafting software packages. The current MoDOT standard for drafting software is Microstation V8 (08.05.02.70) and for design software is Geopak V8 (08.08.03.24). The current version of Geopak does not support direct manipulation of .las files. HDR upgraded to Microstation XM (08.09.04.88) and Geopak XM (08.09.07.28) in order to access the tools that have been developed to work in conjunction with LiDAR survey data sets.

Geopak has suggested workflows for processing LiDAR data and permits users to extract various point classifications. It should be noted that only one Microstation XM drawing was needed to process the .las files. The remaining project drawings were not converted to a new version of Microstation. LiDAR tools are located inside of Geopak XM in the DTM toolset. LiDAR tools facilitate the reduction of large LiDAR survey data sets to a more manageable size and one that represents the area of interest. The reduction of the data set can be accomplished via filtering and/or clipping. The maximum number of points that can be filtered on a machine with 1GB of main memory is approximately 30 million. This limitation necessitates the tiling of LiDAR data sets into smaller packages. The reduced data sets were converted to a binary format (see Figure 26) and then the Geopak triangulated irregular network (.tin) models were generated. These .tin models correspond to the tiling layout of the .las survey data.

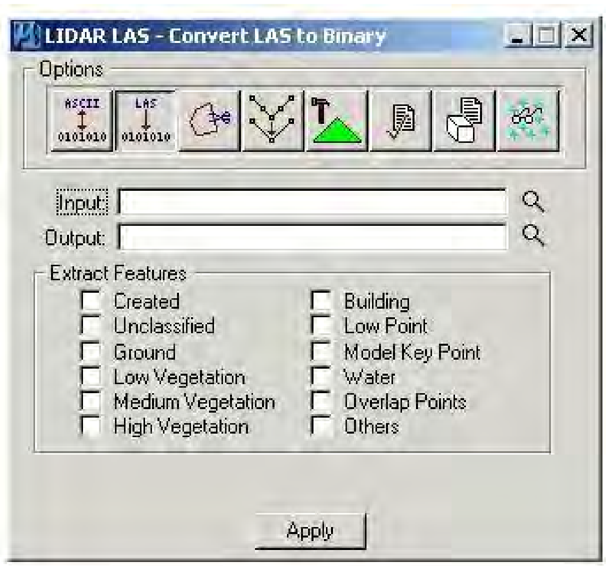


Figure 37 Geopak XM - las import

The contours and triangles from the aerial and mobile survey .tin models were overlaid on the feature graphics from the Sanborn survey. As expected, a very accurate representation of the survey was present in the graphics that were displayed inside of Microstation. When the LiDAR survey data and graphics were referenced into the original data from the photogrammetric survey, a couple of issues were encountered. A shift in the coordinate systems between the two data sets was identified. One data set was compiled using the modified state plane coordinate system and the other was compiled in state plane coordinates. The other issue was with the working units of the Microstation drawings. <u>It is extremely important that all of the drawings contain the same working units and that the units.def file for all users of the data is in the same format. The units.def file is located on the local drive after Microstation is installed on a computer. The default layout of this file places international feet/inches ahead of survey feet/inches in the priority list. Problems arise when one end user is referring to a units.def file that is different than another user. The use of international units can lead to a coordinate shift of approximately two feet per one million feet.</u>

The data sets were revised to correct the issue with state plane coordinates and with the Microstation unit definitions. These data sets were delivered in .xyz at a density of approximately 1 point per foot utilizing bare earth points only. This reduction in point density allowed for a more efficient processing of the data using the standard MoDOT software packages. It was not necessary to use the upgraded version of Microstation since the data sets were .xyz instead of .las.

HDR generated revised .tins for the aerial and mobile data sets using the convert to binary and build triangles toolsets inside of Geopak. XM (08.09.07.28) 14 aerial and 163 mobile .tin models were created. The .tin models were left independent of each other to retain the original tiling layout. <u>The networks can be combined using the merge .tins toolset in the design phase in order to simplify the roadway modeling.</u>

Quality control checks on the surfaces and contours were conducted using Microstation XM and Geopak XM. Several toolsets allow users to evaluate survey data including compare for fit, reporting coordinate ranges, displaying LiDAR points, and elevation differences comparison. The direct .tin to .tin comparison toolset provides a visual representation of the difference in elevation between two .tin models. The user can select an area of interest and define a grid matrix depending on the level of detail that the user would like to utilize.

Results and Discussion

Triangulated Irregular Networks (TIN) Surface Evaluation

The .tin model evaluation was performed using the elevation differences toolset inside of Geopak. The .tin model from the aerial photogrammetry was used as the base model to compare against. The .tin models were not expected to match one another exactly. There is an elevation error that is already present in the .tin model that was produced from the photogrammetric survey. That error from the photogrammetric .tin model to the actual pavement elevation varies depending on the scale of the imagery, the accuracy during mapping, and the frequency of points that are collected for the photogrammetric (aerial film) surface

For example, the aerial LiDAR AB_08.tin was compared to the photogrammetry .tin and a grid of elevation differences was displayed (see Figure 38). Also, the mobile LiDAR 1832.tin and 1833.tin were compared to the photogrammetry .tin and a grid of elevation differences were displayed (see Figure 39). In both of these cases, no consistent pattern for the elevation differences between the LiDAR .tin model and the base model was identified.

Figure 38 Aerial TIN Analysis

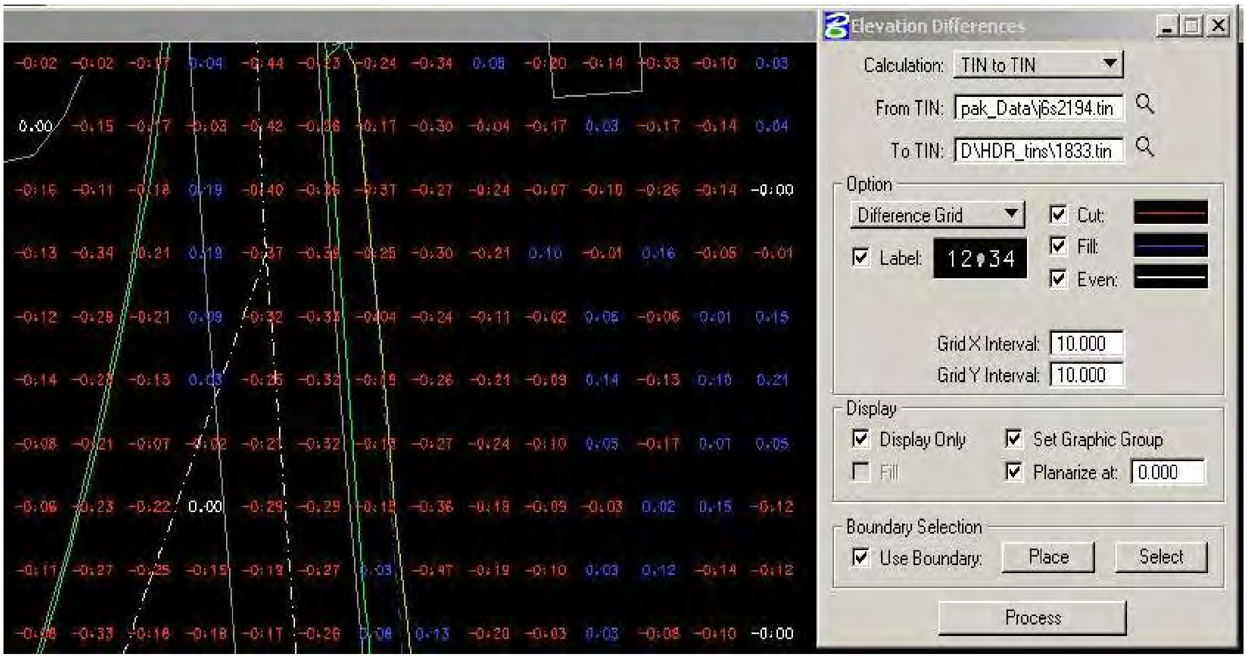


Figure 39 Mobile TIN Analysis

TIN Accuracy Assessment – TIN to Control

Another method of comparing the accuracy of the various .tin models was to utilize the control point data that was hard shot in the field and compare .tin elevations to those records. Approximately 40 control points were located that fell inside the mapped boundaries of the .tin models. One limiting factor in utilizing additional mapped points for comparison was the relatively narrow band that encompassed the photogrammetric .tin. <u>The LiDAR mapping provided broader coverage along the corridor than the photogrammetric mapping.</u>

Volumetric Surface Evaluation

The volumetric surface evaluation was performed using the volume calculations toolset inside of Geopak. The purpose of this analysis was to determine the magnitude of the volumetric variations between the .tin models that were developed through the use of the photogrammetric and LiDAR survey methods. The .tin model from the aerial photogrammetry was used as the base model to compare against. The outside limit of the photogrammetric surface was utilized as the boundary polygon in this process.

The current MoDOT standard for drafting software is Microstation V8 (08.05.02.70) and for design software is Geopak V8 (08.08.03.24). The computer that was utilized for this analysis contained a 3.2 GHz processor, 4 MB of RAM, and was configured with the Windows XP operating system. This configuration was able to run the volumetric analysis for all of the LiDAR .tin models, except for the three largest aerial LiDAR surfaces. These three .tin models were all larger than 285 MB, with the largest .tin model being greater than 353 MB. Several solutions were attempted to resolve this processing problem including running the analysis outside of Projectwise and increasing the size of the paging file for the virtual memory to 16 MB. These methods were not able to process the volumetric calculations on these three surfaces. Ultimately, these three surfaces were analyzed on a computer that contained a 3.0 GHz processor, 8 MB of RAM, and was configured with the Windows 7 64-bit operating system. The large file size of these .tin models necessitated the use of a more powerful computer system in order to analyze the data. The end user can alleviate this issue by breaking the job into smaller segments which will limit the overall size of the .tin model.

The aerial LiDAR surfaces were compared to the photogrammetry .tin and a summary of the volumetric variances was generated (see Table 4). Also, the mobile LiDAR surfaces were compared to the photogrammetry .tin and summary tables were generated (see Table 5).

VOLUMETRIC SURFACE EVALUATION: AERIAL LIDAR

Photogrammetric Surface (.tin)	Aerial Surface (.tin)	Total Cut (CY)	Total Fill (CY)	Balance (CY)
J6S2194	AB_01	1156.357	2716.486	-1560.129
J6S2194	AB_02	1567.799	5285.009	-3717.210
J6S2194	AB_03	1143.224	9860.187	-8716.963
J6S2194	AB_04	182.549	6457.568	-6275.019
J6S2194	AB_05	348.753	9599.499	-9250.746
J6S2194	AB_06	3734.058	12143.923	-8409.865
J6S2194	AB_07	2420.736	7246.539	-4825.803
J6S2194	AB_08	1989.263	4829.369	-2840.106
J6S2194	AB_09	1058.098	4046.028	-2987.930
J6S2194	AB_10	1195.590	11028.903	-9833.313
J6S2194	AB_11	2122.380	5652.902	-3530.522
J6S2194	AB_12	1260.413	6463.625	-5203.212
J6S2194	AB_13	542.307	5311.414	-4769.107
J6S2194	AB_14	1723.551	5081.267	-3357.716
	Total:	**20,445.08**	**95,722.72**	**-75,277.64**

Table 4 Volumetric Surface Evaluation - Aerial LiDAR

VOLUMETRIC SURFACE EVALUATION: MOBILE LIDAR

Photogrammetric Surface (.tin)	Mobile Surface (.tin)	Total Cut (CY)	Total Fill (CY)	Balance (CY)
J6S2194	1704	93.188	805.609	-712.421
J6S2194	1707	5.088	981.315	-976.227
J6S2194	1708	183.564	2480.284	-2296.720
J6S2194	1711	20.390	3361.504	-3341.114
J6S2194	1713	72.125	468.031	-395.906
J6S2194	1714	42.594	744.163	-701.569
J6S2194	1717	119.716	1316.032	-1196.316
J6S2194	1720	7.970	274.772	-266.802
J6S2194	1721	31.153	2306.262	-2275.109
J6S2194	1723	0.000	13.487	-13.487
J6S2194	1724	37.761	1978.646	-1940.885
J6S2194	1725	8.796	262.425	-253.629
J6S2194	1727	23.392	1099.213	-1075.821
J6S2194	1728	7.829	455.849	-448.020
J6S2194	1732	0.017	33.531	-33.514
J6S2194	1733	0.035	70.05	-70.015
J6S2194	1734	0.907	236.448	-235.541
J6S2194	1735	55.309	653.924	-598.615
J6S2194	1736	171.264	1041.613	-870.349
J6S2194	1737	49.059	435.109	-386.050
J6S2194	1740	2.606	2219.214	-2216.608
J6S2194	1741	27.488	4340.876	-4313.388
J6S2194	1742	9.728	4035.421	-4025.693
J6S2194	1743	19.522	2937.763	-2918.241
J6S2194	1744	23.939	1535.105	-1511.166
J6S2194	1745	0.090	1146.383	-1146.293
J6S2194	1748	1.631	2963.946	-2962.315
J6S2194	1753	21.356	3015.522	-2994.166
J6S2194	1756	0.387	376.185	-375.798
J6S2194	1757	18.172	2424.749	-2406.577
J6S2194	1760	1.260	148.962	-147.702
J6S2194	1761	14.763	1770.805	-1756.042
J6S2194	1762	17.966	2375.906	-2357.940

J6S2194		1763		0.007		380.377		-380.370
J6S2194		1766		2.462		1172.247		-1169.785
J6S2194		1767		24.719		1934.055		-1909.336
J6S2194		1768		1.395		493.062		-491.667
J6S2194		1771		8.195		730.646		-722.451
J6S2194		1772		12.707		1514.775		-1502.068
J6S2194		1776		14.621		1496.936		-1482.315
J6S2194		1777		19.534		965.162		-945.628
J6S2194		1778		0.015		106.878		-106.863
J6S2194		1179		13.497		2190.802		-2177.305
J6S2194		1781		100.911		2135.939		-2035.028
J6S2194		1784		49.953		1816.053		-1766.100
J6S2194		1787		47.399		1980.673		-1933.274
J6S2194		1789		2.192		146.515		-144.323
J6S2194		1790		196.463		963.119		-766.656
J6S2194		1792		18.129		543.879		-525.750
J6S2194		1793		273.114		431.790		-158.676
J6S2194		1795		20.864		396.225		-375.361
J6S2194		1796		482.665		605.798		-123.133
J6S2194		1798		40.274		315.042		-274.768
J6S2194		1799		256.067		1010.458		-754.391
J6S2194		1800		101.334		352.185		-250.851
J6S2194		1801		414.187		736.433		-322.246
J6S2194		1802		78.178		811.011		-732.833
J6S2194		1803		179.236		477.011		-297.775
J6S2194		1804		24.521		740.026		-715.505
J6S2194		1805		210.979		968.950		-757.971
J6S2194		1808		486.375		1397.807		-911.432
J6S2194		1811		286.228		1112.963		-826.735
J6S2194		1812		82.304		72.402		9.902
J6S2194		1813		41.441		1008.238		-966.797
J6S2194		1814		31.273		923.186		-891.913
J6S2194		1816		0.023		50.734		-50.711
J6S2194		1817		42.813		1524.619		-1481.806
J6S2194		1820		6.087		2220.167		-2214.080
J6S2194		1822		0.000		0.015		-0.015

J6S2194		1823		27.636		1691.048		-1663.412
J6S2194		1825		0.066		299.632		-299.566
J6S2194		1826		49.201		1048.073		-998.872
J6S2194		1828		5.651		1580.357		-1574.706
J6S2194		1829		59.460		651.048		-591.588
J6S2194		1830		49.376		780.757		-731.381
J6S2194		1831		50.215		606.208		-555.993
J6S2194		1832		178.952		443.119		-264.167
J6S2194		1833		253.809		173.401		80.408
J6S2194		1835		3.502		507.847		-504.345
J6S2194		1836		60.843		3908.234		-3847.391
J6S2194		1837		56.935		685.863		-628.928
J6S2194		1838		0.136		33.793		-33.657
J6S2194		1842		21.986		1455.857		-1433.871
J6S2194		1843		98.544		1914.387		-1815.843
J6S2194		1844		0.910		582.344		-581.434
J6S2194		1845		0.607		573.905		-573.298
J6S2194		1846		58.915		1420.090		-1361.175
J6S2194		1847		29.202		1924.367		-1895.165
J6S2194		1848		2.436		2272.564		-2270.128
J6S2194		1849		0.000		0.123		-0.123
J6S2194		1852		0.000		1021.817		-1021.817
J6S2194		1853		1.118		2379.370		-2378.252
J6S2194		1854		19.766		1133.044		-1113.278
J6S2194		1855		7.260		209.168		-201.908
J6S2194		1857		3.438		804.167		-800.729
J6S2194		1858		114.267		1625.150		-1510.883
J6S2194		1859		72.509		1537.630		-1465.121
J6S2194		1860		79.412		1165.878		-1086.466
J6S2194		1861		146.942		1497.392		-1350.450
J6S2194		1862		1.961		242.965		-241.004
J6S2194		1867		3.108		304.797		-301.689
J6S2194		1868		0.172		318.000		-317.828
J6S2194		1869		0.375		149.580		-149.205
J6S2194		1870		122.533		1308.465		-1185.932
J6S2194		1872		193.204		1512.130		-1318.926

J6S2194		1875		205.567		1285.323		-1079.756
J6S2194		1876		134.034		407.378		-273.344
J6S2194		1877		0.577		301.644		-301.067
J6S2194		1878		268.902		2066.363		-1797.461
J6S2194		1881		175.035		2156.908		-1981.873
J6S2194		1882		134.785		447.333		-312.548
J6S2194		1885		181.946		2015.865		-1833.919
J6S2194		1886		23.178		308.773		-285.595
J6S2194		1888		7.059		469.674		-462.615
J6S2194		1889		118.000		2893.799		-2775.799
J6S2194		1890		0.006		48.513		-48.507
J6S2194		1892		18.815		1022.640		-1003.825
J6S2194		1893		238.130		1971.119		-1732.989
J6S2194		1894		8.356		136.891		-128.535
J6S2194		1896		14.945		1439.861		-1424.916
J6S2194		1897		151.143		1916.487		-1765.344
J6S2194		1900		102.256		817.609		-715.353
J6S2194		1901		0.072		224.994		-224.922
J6S2194		1902		74.268		1078.075		-1003.807
J6S2194		1903		13.932		263.321		-249.389
J6S2194		1904		21.091		2159.238		-2138.147
J6S2194		1905		10.138		874.365		-864.227
J6S2194		1906		79.139		220.569		-141.430
J6S2194		1913		3.606		308.985		-305.379
J6S2194		1914		70.399		1022.815		-952.416
J6S2194		1915		46.821		1715.875		-1669.054
J6S2194		1916		316.809		1779.191		-1462.382
J6S2194		1917		1309.850		1557.497		-247.647
J6S2194		1918		132.752		640.859		-508.107

Total: **10,295.29** **151,349.82** **-141,054.53**

Table 5 Volumetric Surface Evaluation -Mobile LiDAR

The results of the volumetric analysis indicate that the difference between the photogrammetric surface and the aerial LiDAR surface is approximately 75,000 cubic yards of fill material. The difference between the photogrammetric surface and the mobile LiDAR surface is approximately 141,000 cubic yards of fill material. Although these values are representative of the relative variations between the surface elevations, they are misleading as to the accuracy that can be expected from the various surveying methods. The comparison of the LiDAR techniques to the photogrammetric methods will not provide an accurate volumetric analysis as related to the actual in place field conditions. This is due to several factors including, but not limited to, the shadowing affect of buildings and knolls on the mobile scanner, the accuracy of the extraction of the photogrammetric data, and the impact of vegetation on the LiDAR scanning system.

In order to illustrate one example of the difficulty in evaluating the LiDAR surfaces against the photogrammetric surfaces, the contours for each one of the surfaces were draped over one another (see Figure 40). At this location, the LiDAR data sets maintain a fairly consistent pattern with one another and indicate a uniform roadway crown. The photogrammetric contours do not illustrate the crown along the existing roadway. The lack of the crown could be that the centerline of the existing pavement was not collected during the initial data extract of the photogrammetric survey or the breakline for this data was not incorporated into the photogrammetric .tin model. This issue leads to approximately a six inch differential in the surfaces along the existing roadway. This elevation difference contributes to the overall fill volumes that were generated in the volumetric calculations analysis.

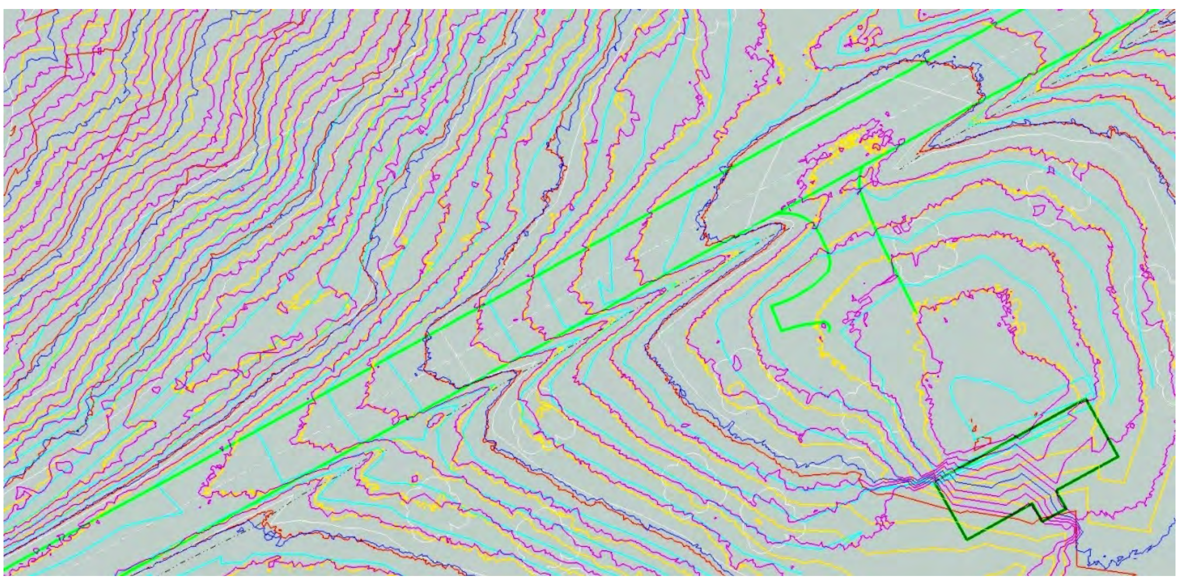


Figure 40 Volumetric Contour Evaluation

Tin Surface: Existing Contour Comparison		
Tin Model:	**Major Contour (5' interval):**	**Minor Contour (1' interval):**
Photogrammetric	White	Light Blue
Aerial LiDAR	Dark Blue	Magenta
Mobile LiDAR	Red	Orange

The ability to analyze the LiDAR surfaces against the existing photogrammetric surface is limited by many factors. This analysis provides the ability to calculate relative volumetric differences between the surfaces, but the analysis is inconclusive as to what survey method will provide for more accuracy in the roadway modeling phase of a project and potentially fewer construction overruns in the field

A matrix of the control point elevations and the elevations contained within the various .tin models is shown below (Table 6). <u>It can be seen from the results that the mapping from the aerial LiDAR survey provides very accurate data.</u> This mapping was generated from the filtered bare earth LiDAR file that provided 1 point every foot. <u>The quality of this survey will allow designers to accurately and efficiently complete their projects.</u>

TIN SURFACE EVALUATION: CONTROL POINTS vs. TIN MODELS

Pt. ID.	E (X)	N (Y)	Elev (Z)	Photo	Dz	Aerial	Dz	Mobile	Dz
100	675819.843	956830.290	589.937	589.657	0.280	590.180	-0.243	590.076	-0.139
101	672594.330	959419.902	730.758	730.947	-0.189	730.640	0.118	730.602	0.156
102	672229.392	959886.600	739.758	739.669	0.089	739.787	-0.029	739.557	0.201
103	669360.917	963103.603	749.989	750.246	-0.257	750.040	-0.051	750.07	-0.081
104	668586.001	963356.133	746.529	745.810	0.719	746.370	0.159	746.525	0.004
105	664512.056	964719.789	810.718	810.567	0.151	810.743	-0.025	810.824	-0.106
106	664564.789	965658.647	801.845	802.138	-0.293	801.961	-0.116	801.944	-0.099
107	664048.014	970484.107	766.045	765.940	0.105	766.047	-0.002	766.080	-0.035
108	663948.923	975720.992	761.436	761.196	0.240	761.609	-0.173	761.749	-0.313
109	664470.975	976252.550	745.678	745.668	0.010	745.562	0.116	745.598	0.080
110	670220.247	981057.825	675.429	675.132	0.297	675.421	0.008	675.484	-0.055
111	670439.937	981659.389	664.509	664.367	0.142	664.499	0.010	664.427	0.082
115	666592.348	978984.694	726.046	725.073	0.973	726.149	-0.103	726.263	-0.217
116	666395.943	977593.560	706.947	706.409	0.538	706.918	0.029	706.822	0.125
304	675156.991	956847.521	626.337	626.207	0.130	626.408	-0.071	626.255	0.082
306	674074.488	957064.723	649.747	649.728	0.019	649.824	-0.077	649.863	-0.116
309	673470.524	957164.647	698.809	698.805	0.004	698.941	-0.132	698.787	0.022
314	670813.886	962401.602	755.699	755.492	0.207	755.817	-0.118	755.798	-0.099
316	670460.591	963229.993	768.341	767.803	0.538	768.286	0.055	768.352	-0.011
323	664766.784	964419.895	785.906	785.984	-0.078	786.154	-0.248	786.16	-0.254
333	664218.060	974517.220	757.299	757.299	0.000	757.410	-0.111	757.392	-0.093
340	666677.161	978940.356	722.564	722.599	-0.035	722.616	-0.052	722.681	-0.117
344	669636.814	980012.394	698.960	698.929	0.031	699.048	-0.088	699.039	-0.079
504	667735.745	978964.684	717.749	717.546	0.203	717.607	0.142	717.783	-0.034
508	669775.443	980173.814	693.705	693.306	0.399	693.686	0.019	693.658	0.047
512	668638.020	979161.125	710.611	710.424	0.187	710.702	-0.091	710.507	0.104
516	665838.636	976991.810	734.931	734.320	0.611	734.823	0.108	734.801	0.130
520	664088.890	975826.410	756.061	755.249	0.812	755.793	0.268	755.968	0.093
522	664128.058	974924.102	765.835	765.572	0.263	765.932	-0.097	765.743	0.092
525	664175.593	972812.110	781.362	781.454	-0.092	781.434	-0.072	781.261	0.101
530	664189.653	969750.119	767.311	767.556	-0.245	767.321	-0.010	767.225	0.086
532	664599.540	968558.619	771.172	771.079	0.093	771.094	0.078	771.036	0.136
534	664767.520	967300.751	784.280	783.845	0.435	784.202	0.078	784.166	0.114
537	664660.020	966036.048	798.228	798.142	0.086	798.362	-0.134	798.277	-0.049
540	664689.471	964432.725	795.156	795.077	0.079	795.314	-0.158	795.158	-0.002
548	669482.916	963082.494	753.565	753.043	0.522	753.631	-0.066	753.478	0.087
550	670499.593	963166.654	766.433	766.292	0.141	766.318	0.115	766.381	0.052
553	670850.046	962370.619	758.194	758.282	-0.088	757.827	0.367	758.038	0.156
558	672261.475	959851.527	738.686	738.701	-0.015	738.562	0.124	738.507	0.179
560	672783.734	959242.455	727.662	727.498	0.164	727.711	-0.049	727.536	0.126
562	673474.543	957222.722	700.526	700.224	0.302	700.558	-0.032	700.437	0.089
566	675540.481	956828.730	603.556	603.132	0.424	603.319	0.237	603.343	0.213
				RMSE =	**0.338**	**RMSE =**	**0.130**	**RMSE =**	**0.124**

Table 6 - Photogrammetric- vs Aerial and Mobile TIN Analysis

Planimetric Feature Evaluation

The evaluation of the planimetric features was performed using the distance toolset inside of Microstation. During the initial phase of this process, it was noted that the analysis of the aerial survey features and the LiDAR survey features may not provide quality results. This is the result of the lack of multiple field cross section shots to compare the survey data against.

An example of how the lack of field survey shots affects the planimetric feature evaluation process is represented in the mapping of the existing buildings and structures. The aerial photography mapping and the LiDAR survey mapping give similar building shapes, but they are not exactly alike (see Figure 41). This may be a result of the accuracy of the initial survey, the expertise of the individuals performing the mapping and translating the data into a CAD design package, or a problem with the coordinates or units that the project is currently using.

Figure 41 Feature - Position Analysis

Since there are no hard data survey points at the existing building corners, the measurement of the offset between the mapped shapes is subjective. The ability to determine which data is more accurate is limited due to the uncertainty in where the error in the planimetric features could have originated.

The collection of field cross sections and multiple shots on existing structures would allow for a more effective comparison of the horizontal accuracy of the mapped features from the initial aerial survey and the secondary LiDAR survey. Ideally, those sections would be located along the length of the corridor in areas where more relief is present. The presence of ditches or slope limits in these areas would provide additional opportunities to compare linear roadway features to the field cross sections. The use of these sections would also help in confirming that a shift in the mapping is not present. A north/south shift may not be detected on a tangent section of roadway that runs north/south.

Another method of comparing the accuracy of the planimetric features was attempted. The initial control file for the aerial photography contained a couple points that were described as "edge of asphalt pavement." The offsets from the mapped features from the surveys to these control points were measured in Microsation (see Figure 42 and 43)

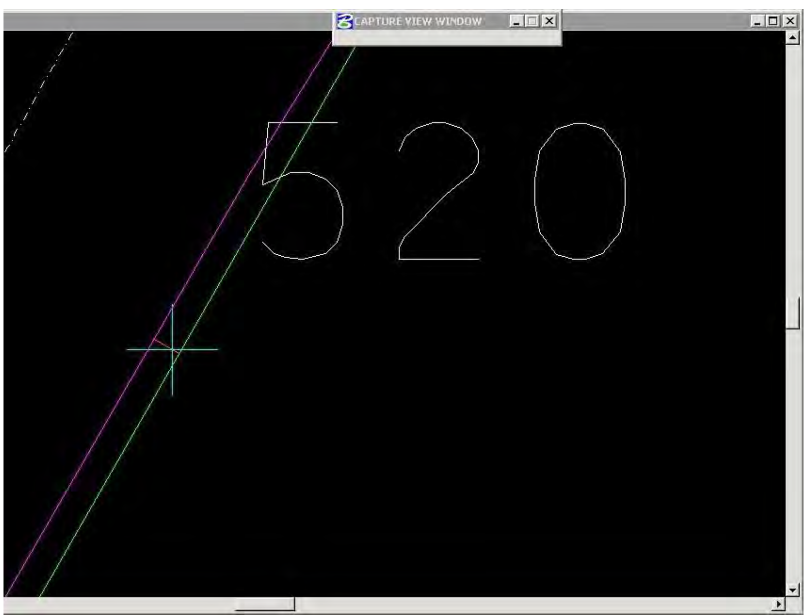


Figure 42 Point 520

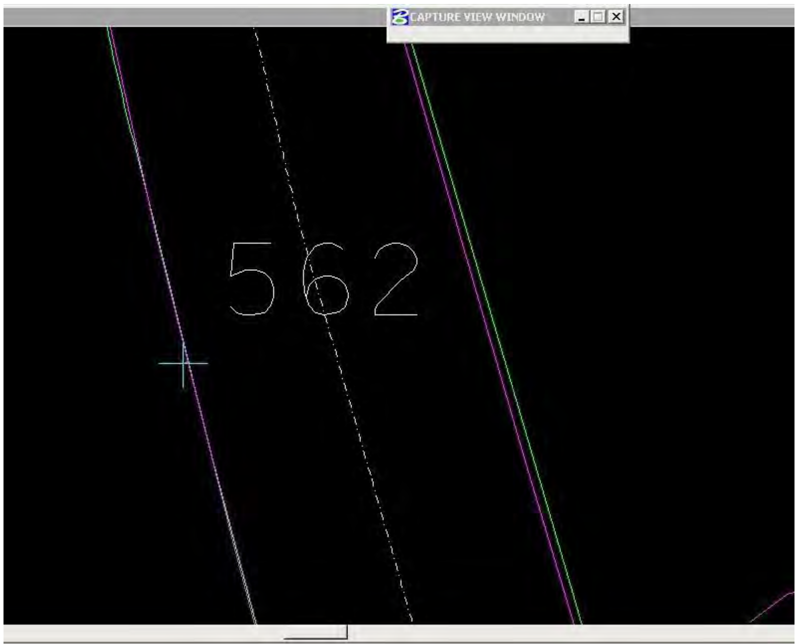


Figure 43 Point 562

The horizontal offsets for the mapped features to Control Point 520 were 1.14’ and 0.45’ for the photogrammetric (purple) and LiDAR (green) survey, respectively. The horizontal offsets for the mapped features to Control Point 562 were 0.53’ and 0.59’ for the photogrammetric (purple) and LiDAR (green) survey, respectively. The accuracy of the planimetric features at both of these locations is dependent on many factors, but the offsets seem to fall within an acceptable range in order to be able to advance to the design phase of a project.

Cost Analysis Matrix

Below is an estimate of cost impacts based on the technologies evaluated. Data processing and feature extraction is based on the road, vegetation, poles and buildings as per sample data provided for a sample 7 mile corridor.

Traditional Survey Design Cost							
Task	**Persons**	**Hours**	**Hourly Cost**	**Labor Cost**	**Person Days**	**$/Mile**	**NOTES**
Administration	Surveying Manager, PLS	16	$145	$2,320	2.0	$331	
Courthouse Research	Survey Technician	32	$75	$2,400	4.0	$343	
Utility Research	Survey Technician	24	$75	$1,800	3.0	$257	
Establish Horizontal and Vertical Control	Survey Crew Chief	60	$130	$7,800	7.5	$1,114	GPS
	Survey Technician			$0			
Topographic Survey of Roadway	Survey Crew Chief	550	$130	$71,500	68.8	$10,214	GPS
	Survey Technician			$0			
Drafting Mapping	Survey Technician	543	$75	$40,725	67.9	$5,818	
Survey Computations	Project Designer	32	$90	$2,880	4.0	$411	
QC/QA	Surveying Manager, PLS	24	$90	$2,160	3.0	$309	
TOTAL SURVEYING		**1281**		**$131,585**	**160.1**	**$18,798**	

Table 7 Cost Analysis Matrix - Traditional Survey Design

Aerial Lidar							
Task	Persons	Hrs	Hourly Cost	Labor Cost	Person Days	$/Mile	NOTES
Planning	Project Manager	8	$120	$960	1.0	$137	
Survey - Planning	Survey Manager PLS	8	$145	$1,160	1.0	$166	
Establish - Base Station	Survey Crew Chief/Technician	16	$130	$2,080	2.0	$297	3 Base Stations
Locate Check Points	Survey Crew Chief/Technician	40	$130	$5,200	5.0	$743	60 Check Points - No Panels
Survey Computations /QA	Survey Manager PLS	20	$90	$1,800	2.5	$257	
Field Collection	Pilot	6	$122	$731	0.8	$104	
	Data Acq Technician	6	$69	$417	0.8	$60	
Calibration	Sr Lidar Analyst	8	$194	$1,554	1.0	$222	
Point Cloud Creation/Editing	Lidar Tech I	120	$68	$8,214	15.0	$1,173	
Feature Extraction	Lidar Tech I	40	$68	$2,738	5.0	$391	
	Compiler	80	$71	$5,680	10.0	$811	
QC	Sr Lidar Analyst	60	$194	$11,658	7.5	$1,665	
Product Generation	Lidar Tech II	20	$85	$1,693	2.5	$242	
Aircraft		6	$963	$5,780	0.8	$826	
Aerial Lidar		6	$1,431	$8,586	0.8	$1,227	
TOTAL AERIAL LIDAR		**444**		**$58,250**	**55.5**	**$8,321**	

Table 8 Cost Analysis Matrix - Aerial LiDAR

Mobile Lidar							
Task	Persons	Hrs	Hourly Cost	Labor Cost	Person Days	$/Mile	NOTES
Planning	Project Manager	8	$120	$960	1.0	$137	
Survey - Planning	Survey Manager PLS	8	$145	$1,160	1.0	$166	
Establish - Base Station	Survey Crew Chief/Technician	16	$130	$2,080	2.0	$297	3 Base Stations
Locate Check Points	Survey Crew Chief/Technician	40	$130	$5,200	5.0	$743	60 Check Points No Panels
Survey Computations /QA	Survey Manager PLS	20	$90	$1,800	2.5	$257	
Field Collection	Sr Lidar Analyst	4	$194	$776	0.5	$111	
	Lidar Tech 1	4	$68	$272	0.5	$39	
Calibration	Sr Lidar Analyst	60	$194	$11,640	7.5	$1,663	
Point Cloud Creation/Editing	Lidar Tech 1	300	$68	$20,400	37.5	$2,914	
Feature Extraction/CADD	Lidar Tech 1	50	$68	$3,400	6.3	$486	
	Compiler	80	$71	$5,680	10.0	$811	
QC	Sr Lidar Analyst	80	$194	$15,520	10.0	$2,217	
Product Generation	Lidar Tech II	40	$85	$3,400	5.0	$486	
Vehicle		8	$25	$200	1.0	$29	
Mobile Laser System		8	$1,150	$9,200	1.0	$1,314	
TOTAL MOBILE LIDAR		726		**$81,688**	**90.8**	**$11,670**	

Table 9 Cost Analysis Matrix - Mobile LiDAR

Static Lidar							
Task	Persons	Hrs	Hourly Cost	Labor Cost	Person Days	$/Mile	NOTES
Planning	Project Manager	20	$51	$1,011	2.5	$144	
Survey - Planning	Survey Manager PLS	8	$145	$1,160	1.0	$166	
Establish Horizontal Vertical Control	Survey Crew Chief/Technician	60	$130	$7,800	7.5	$1,114	4 GPS Monument - Base Stations
		0		$0	0.0	$0	
Survey Computations /QA	Survey Manager PLS	32	$90	$2,880	4.0	$411	
Field Collection - Static Scanner	Survey Crew Chief/Technician	274	$130	$35,620	34.3	$5,089	
Approx 183 Setups @ 1.5 hrs			$28	$0	0.0	$0	
Calibration	Sr Lidar Analyst	183	$194	$35,502	22.9	$5,072	
Point Cloud Creation/Editing	Lidar Tech I	549	$68	$37,332	68.6	$5,333	
Feature Extraction/CADD	Lidar Tech II	140	$68	$9,520	17.5	$1,360	
	CADD/GIS	60	$71	$4,260	7.5	$609	
QC	Sr Lidar Analyst	80	$194	$15,520	10.0	$2,217	
Product Generation	Lidar Tech II	40	$85	$3,400	5.0	$486	
System		254	$200	$50,800			
TOTAL STATIC LIDAR		**1700**		**$204,805**	**212.5**	**$29,258**	

Table 10 Cost Analysis Matrix - Static LiDAR

Conventional Aerial Mapping							
Task	**Persons**	**Hrs**	**Hourly Cost**	**Labor Cost**	**Person Days**	**$/Mile**	**Notes**
Planning	Project Manager	8	$120	$957	1.0	$137	
Survey - Planning	Survey Manager PLS	8	$145	$1,160	1.0	$166	
Establish Horizontal Vertical Control	Survey Crew Chief/Technician	60	$130	$7,800	7.5	$1,114	4 GPS Monments + 85 Check Points
Locate Panel Points	Survey Crew Chief/Technician	130	$130	$16,900	16.3	$2,414	52 Panel Points
Survey Computations /QA	Survey Manager PLS	44	$90	$3,960	5.5	$566	
Aerial Collection	Pilot	4	$92	$367	0.5	$52	82 Exp -DMC
	Photographer	4	$68	$270	0.5	$39	
Image Processing	Image Processing Technician	12	$55	$658	1.5	$94	
Aerial Triangulation	Sr Photogrammetrist	20	$94	$1,884	2.5	$269	
Compilation	Stereo Compiler	120	$71	$8,488	15.0	$1,213	
GIS/CADD	CADD Technician	80	$73	$5,854	10.0	$836	
OrthoRectification	Ortho Technician	40	$50	$2,008	5.0	$287	
QC	Project Manager	8	$120	$957	1.0	$137	
Aircraft		6	$392	$2,351	0.8	$336	
Analog Camera		4	$405	$1,620	0.5	$231	
TOTAL CONVENTIONAL MAPPING		**548**		**$55,234**	**68.5**	**$7,891**	

Table 11 Cost Analysis Matrix - Conventional Mapping

Summary	Hrs	Labor Cost	Person Days	$/Mile
Traditional Survey Design	1281	$131,585	160.1	$18,798
Aerial Lidar	444	$58,250	55.5	$8,321
Mobile Lidar	726	$81,688	90.8	$9,933
Static Lidar	1700	$204,805	212.5	$29,258
Conventional Aerial Mapping	548	$55,234	68.5	$7,891
****Cost Estimated on 7 Mile corridor - Mobilization cost and ODC's not included				

Table 12 Cost Analysis Summary

The above summary of costs is based on estimates of the level of effort and costs associated with equipment and personnel. Costs will vary based on final scope of work, level of detail, approach to the tasks, technology employed, location of personnel and equipment and other variable market factors.

Schedule Comparison

The comparison is based on 7 mile project for MODOT Operations and listed as equivalent person days based on a standard 8 hour day. Collection times are for "on-line" times and not mobilization to project site.

Traditional Survey Design Cost					
Task	**Persons**	**Hours**	**Person Days**	**Staff Available**	**Schedule**
Administration	Surveying Manager, PLS	16	2.0	1.0	2.0
Courthouse Research	Survey Technician	32	4.0	1.0	4.0
Utility Research	Survey Technician	24	3.0	1.0	3.0
Establish Horizontal and Vertical Control	Survey Crew Chief	60	7.5	2.0	3.8
	Survey Technician				
Topographic Survey of Roadway	Survey Crew Chief	550	68.8	6.0	11.5
	Survey Technician				
Drafting Mapping	Survey Technician	543	67.9	4.0	17.0
Survey Computations	Project Designer	32	4.0	1.0	4.0
QC/QA	Surveying Manager, PLS	24	3.0	1.0	3.0
TOTAL SURVEYING		**1281**	**160.1**		**48.2**

Table 13 Schedule Traditional Survey

Aerial Lidar					
Task	Persons	Hrs	Person Days	Staff Available	Schedule
Planning	Project Manager	8	1.0	1.0	1.0
Survey - Planning	Survey Manager PLS	8	1.0	1.0	1.0
Establish - Base Station	Survey Crew Chief/Technician	16	2.0	2.0	1.0
Locate Check Points	Survey Crew Chief/Technician	40	5.0	2.0	2.5
Survey Computations /QA	Survey Manager PLS	20	2.5	1.0	2.5
Field Collection	Pilot	6	0.8	1.0	0.8
	Data Acq Technician	6	0.8	1.0	0.8
Calibration	Sr Lidar Analyst	8	1.0	1.0	1.0
Point Cloud Creation/Editing	Lidar Tech I	120	15.0	3.0	5.0
Feature Extraction	Lidar Tech I	40	5.0	1.0	5.0
	Compiler	80	10.0	1.0	10.0
QC	Sr Lidar Analyst	60	7.5	1.0	7.5
Product Generation	Lidar Tech II	20	2.5	1.0	2.5
Aircraft		6	0.8		
Aerial Lidar		6	0.8		
TOTAL AERIAL LIDAR		**444**	**55.5**		**40.5**

Table 14 Schedule Aerial LiDAR

Mobile Lidar					
Task	**Persons**	**Hrs**	**Person Days**	**Staff Available**	**Schedule**
Planning	Project Manager	8	1.0	1.0	1.0
Survey - Planning	Survey Manager PLS	8	1.0	1.0	1.0
Establish - Base Station	Survey Crew Chief/Technician	16	2.0	2.0	1.0
Locate Check Points	Survey Crew Chief/Technician	40	5.0	2.0	2.5
Survey Computations /QA	Survey Manager PLS	20	2.5	1.0	2.5
Field Collection	Sr Lidar Analyst	4	0.5	1.0	0.5
	Lidar Tech 1	4	0.5	1.0	0.5
Calibration	Sr Lidar Analyst	60	7.5	1.0	7.5
Point Cloud Creation/Editing	Lidar Tech 1	300	37.5	3.0	12.5
Feature Extraction/CADD	Lidar Tech 1	50	6.3	2.0	3.1
	Compiler	80	10.0	1.0	10.0
QC	Sr Lidar Aanalyst	80	10.0	1.0	10.0
Product Generation	Lidar Tech II	40	5.0	1.0	5.0
Vehicle		8	1.0		
Mobile Laser System		8	1.0		
TOTAL MOBILE LIDAR		726	**90.8**		**57.1**

Table 15 Schedule Mobile LiDAR

Static Lidar					
Task	**Persons**	**Hrs**	**Person Days**	**Staff Available**	**Schedule**
Planning	Project Manager	20	2.5	1.0	2.5
Survey - Planning	Survey Manager PLS	8	1.0	1.0	1.0
Establish Horizontal Vertical Control	Survey Crew Chief/Technician	60	7.5	2.0	3.8
		0	0.0		
Survey Computations /QA	Survey Manager PLS	32	4.0	1.0	4.0
Field Collection - Static Scanner	Survey Crew Chief/Technician	274	34.3	6.0	5.7
Approx 183 Setups @ 1.5 hrs			0.0		
Calibration	Sr Lidar Analyst	183	22.9	1.0	22.9
Point Cloud Creation/Editing	Lidar Tech I	549	68.6	3.0	22.9
Feature Extraction/CADD	Lidar Tech II	140	17.5	2.0	8.8
	CADD/GIS	60	7.5	1.0	7.5
QC	Sr Lidar Analyst	80	10.0	1.0	10.0
Product Generation	Lidar Tech II	40	5.0	1.0	5.0
System		254			
TOTAL STATIC LIDAR		**1700**	**212.5**		**94.0**

Table 16 Schedule Static LiDAR

Conventional Aerial Mapping					
Task	**Persons**	**Hrs**	**Person Days**	**Staff Available**	**Schedule**
Planning	Project Manager	8	1.0	1.0	1.0
Survey - Planning	Survey Manager PLS	8	1.0	1.0	1.0
Establish Horizontal Vertical Control	Survey Crew Chief/Technician	60	7.5	2.0	3.8
Locate Panel Points	Survey Crew Chief/Technician	130	16.3	2.0	8.1
Survey Computations /QA	Survey Manager PLS	44	5.5	1.0	5.5
Aerial Collection	Pilot	4	0.5	1.0	0.5
	Photographer	4	0.5	1.0	0.5
Image Processing	Image Processing Technician	12	1.5	1.0	1.5
Aerial Triangulation	Sr Photogrammetrist	20	2.5	1.0	2.5
Compilation	Stereo Compiler	120	15.0	2.0	7.5
GIS/CADD	CADD Technician	80	10.0	2.0	5.0
OrthoRectification	Ortho Technician	40	5.0	1.0	5.0
QC	Project Manager	8	1.0	1.0	1.0
Aircraft		6	0.8		
Analog Camera		4	0.5		
TOTAL CONVENTIONAL MAPPING		**548**	**68.5**		**42.9**

Table 17 Schedule Conventional Mapping

Summary	Person Hrs	Schedule		
Traditional Survey Design	1281	48.2		
Aerial Lidar	444	40.5		
Mobile Lidar	726	57.1		
Static Lidar	1700	94.0		
Conventional Aerial Mapping	548	42.9		
****Schedule is based on staff assigned for concurrent activties				

Table 18 Schedule Summary

Traditional Survey Deliverables	Aerial/Mobile and Static LiDAR Additional Deliverables	Conventional Aerial Mapping Additional Deliverables
Utility services, both above and below ground	Raw Point Clouds	AT Files - Stereo Imagery, Orthos
Parcel lines	Classified Point Clouds - Bare Earth, Buidlings, Vegetation,	
Right of way lines -(both to be based on field survey control and record title information)		
DGN FILE FEATURES	DGN FILE FEATURES	DGN FILE FEATURES
Buildings, Culverts, Drain Lines, Gravel Road (edge), Road Paved (Edge of Pavement) Ground Mount Signs, Power Poles, Tree, Curb, Drop Inlet, Fence, High Voltage Power Poles, Impounded or Standing Water, Light Poles,Sidewalk (edge),Sign Boards,Stockpiles,	Buildings, Culverts, Drain Lines, Gravel Road (edge), Road Paved (Edge of Pavement) Ground Mount Signs, Power Poles, Tree, Curb, Drop Inlet, Fence, High Voltage Power Poles, Impounded or Standing Water, Light Poles,Sidewalk (edge),Sign Boards,Stockpiles,	Buildings, Culverts, Drain Lines, Gravel Road (edge), Road Paved (Edge of Pavement) Ground Mount Signs, Power Poles, Tree, Curb, Drop Inlet, Fence, High Voltage Power Poles, Impounded or Standing Water, Light Poles,Sidewalk (edge),Sign Boards,Stockpiles,
DTM - GeoPAK Format	DTM - GeoPAK Format	DTM - GeoPAK Format

Table 19 Feature Assumptions for Costs and Schedule

There are a number variables for each project including available staff and equipment, location from home office that affect schedule durations and assumptions of available staff and equipment are listed by task in tables above.

Matrix of Safety Impacts

A sample of potential safety impacts and benefits of the various technology approaches

TASK	Aerial LiDAR	Comments	Mobile LiDAR	Comments
Planning	Low	Office	Low	Office
Ground Survey- base Stations	Low	Remote or controlled location	Low	Remote or Controlled Location
Ground Survey –Control	Med	Check point collection	Med	1 or 2 survey points/mile
Data Collection	NA	Low- Aerial	Low	Collected in traffic
Traffic Control	NA	NA- Aerial	NA	Collected at posted speed
Road Access	NA	NA- Aerial	Low	Collect on any accessible road/track/trail

TASK	Static LiDAR	Comments	Traditional Survey	Comments
Planning	Low	Office	Low	Office
Ground Survey- base Stations	Med	Near project – road area	Med	Near Road Project
Ground Survey –Control	High	Near project – road area	High	Near project – road area
Data Collection	High	Edge of road /on road	High	Edge of road /on road
Traffic Control	High	Required for safety-shoulder/lane closures	High	Required for safety-shoulder/lane closures
Road Access	High	Speed and cone zones	High	Speed and cone zones

TASK	Conventional Aerial	Comments
Planning	Low	Office
Ground Survey- base Stations	Low	Remote or controlled location
Ground Survey –Control	Med	Check point collection
Data Collection	NA	Low- Aerial
Traffic Control	NA	NA- Aerial
Road Access	NA	NA- Aerial

Table 20 Matrix of Safety Impacts

Additional Information and Feature Matrix

Below is a sampling of potential features that can be “mapped” using the various technologies.

Feature	Aerial LiDAR	Mobile LiDAR	Static LiDAR	Traditonal Aerial
Curb	Restricted	YES	YES Y	ES
Gutter/Drain	Yes	YES	YES	YES
Traffic signal	NO	YES	YES	NO
Traffic poles	NO	YES	YES	YES
Road and Local Terrain Information	YES	YES	YES	YES
Parking Meters	NO	YES	YES	NO
Walls	YES	YES	YES	YES
Obstruction in the right of way	YES	YES	YES	Restricted
Manholes N	O	YES	YES	YES
Sidewalks	YES	YES	YES	YES
Overhead Clearance	NO	YES	YES	NO
Lights	Restricted	YES	YES	Restricted
Utility Wires and Connections	Restricted	YES	YES	Restricted
Garbage Cans	NO	YES	YES	NO
Benches	NO	YES	YES	NO
Fences	NO	YES	YES	Restricted
Guardrails/Barriers	NO	YES	YES	YES
Retaining Walls	Restricted	YES	YES	YES
Vegetation - Line of Site obstructions	Restricted	YES	YES	Restricted
**Restricted - Limited complete feature capture				

Table 21 Additional Features Matrix

Current State of the Industry

Currently there are two professional organizations that are working to create “standards” for the practice of LiDAR data collection to support geo-spatial requirements:

1. ASPRS – American Society of Photogrammetry and Remote Sensing- Working with Government, Academic and commercial company representation they have formed working committees to develop Guidelines and Standards for LiDAR Based technologies. Publications include Digital Elevation Model Technologies & Applications 1st and 2nd Editions, LAS Data format standards. ASPRS formed a new sub-committee for Mobile Mapping Technologies at their Spring 2010 conference to address this new technology.[6]
2. ASTM -American Society for Testing and Materials – Technical Committee E57 on 3D Imaging System ASTM – E2641. This committee addresses issues related to 3D imaging systems, which include, but are not limited to laser scanners (also known as LADAR or laser radars) and optical range cameras (also known as flash LADAR or 3D range cameras). Members include manufacturers, federal agencies, design professionals, professional societies, and trade associations. The committee released in March 2010 the Safe Application of Three Dimensional Imaging Technology guideline document.

In addition The Department of Homeland Security, Federal Emergency Management Agency (FEMA) has released guidance for use of Aerial LiDAR in the publication: Guideline and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying (April 2003). The United States Geological Survey (USGS) has released a document for aerial LiDAR Mapping: US Geological Survey National Geospatial Program LiDAR Guidelines and Base Specification Version 13 ILMF 2010, February 22, 2010.

[6] Graham L. Mobile Mapping Systems Overview PE&RS March 2010

Data Accuracy

The bare earth LiDAR and mobile data sets were tested against supplied control data (full results Appendix A) with results for the mobile bare earth surface. (Units: US Survey Feet, dz = difference in elevation)

		MOBILE DATA		Aerial Data	
		US Feet	cm	US Feet	cm
Average dz		-0.002	+0.06	-0.019	-0.57
Minimum dz		-0.196	-5.97	-0.472	-14.39
Maximum dz		+0.338	+10.3	+0.318	+9.69
Average magnitude		+0.104	+3.17	+0.135	+4.11
Root mean square		+0.0126	+3.84	+0.173	+5.27
Std deviation		+0.128	+3.90	+0.173	+5.27

Table 22 Mobile and Aerial Data Accuracy

Based on other research it is anticipated that the mobile system should meet a vertical accuracy of 0.03m[7], . The manufacturer specifications indicate a vertical accuracy of (+/- 5cm)[8]. The sensor and survey has performed within the expected accuracy range for the survey.

The aerial surface accuracy is within expectations for aerial LiDAR.

Both surfaces meet the requirement for 1 foot contour accuracy of NSSDA RMSEz of 0.30ft (9.25 cm). [9]

Both surfaces meet the requirement for photogrammetric mapping accuracy for 1 foot contours in accordance with Table 238.1.5.1 MoDOT Engineering Policy Guide.[10]

[7] Barber D,Mills J, Smith-Voysey S –Geometric Validation of a ground-based mobile laser scanning system, ISPRS Journal of Photogrammetry and Remote Sensing,

[8] Optech Canada, Lynx System Specification

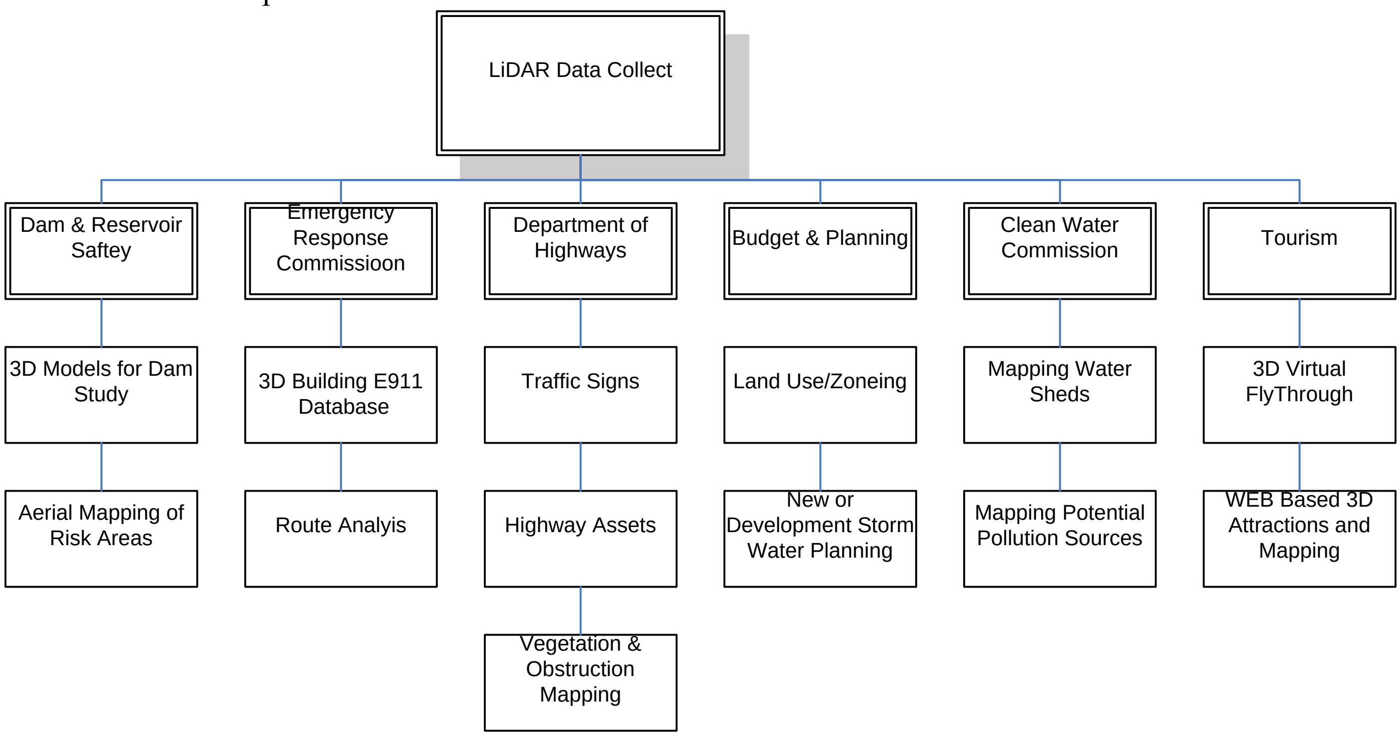
[9] ASPRS Guidelines Vertical Accuracy reporting for LiDAR Data V11.0 May 24,2004

[10] MoDOT Engineering Policy Guide 238.1 http://epg.modot.mo.gov/index.php?title=238.1_Photogrammetric_Surveying#238.1.15_Accuracy

Conclusion

Mobile Laser Mapping technology offers new methods to collect immense amounts of accurate information in the field, reducing field survey time and minimizing the potential safety risks to ground crews traditionally collecting this type of data. As this technology is relatively new in the marketplace there are many hurdles in terms of execution, software and information content to be developed. The ability to collect the data at highway speeds and moving the "survey" from the field to the office will reduce the return to field costs for additional or missed features.

Additional benefits to MoDOT includes potential overall MoDOT project cost savings if data and cost sharing agreements are in place to distribute and share the data with other State, County and City organizations. This would allow the "collect once use many" model for other agencies that could benefit from access to the information content of other roadway features related to their needs for example:



Other potential data sharing opportunities without additional field costs

a. Highway and traffic control signs,
b. Sidewalks, curbs and gutters
c. Parking meters and signs
d. Fire hydrants, manholes, drains
e. Standing water locations;
f. Vegetation for obstruction mapping and urban planning
g. utility organizations can extract/ create inventory:
    a. transformers,

b. poles,
c. wires,

The collection times for the mobile LiDAR is twice aerial but less than 25% of static surveying, while collecting more than 6 times as much data and potential information content as the aerial LiDAR.

A key observation that is clearly significant is the additional amount of processing time and investment in hardware and software required for the mobile datasets. Estimates for this investment are as high as an additional $250,000 [11] or companies that invest in the hardware and software for post processing mobile mapping. This is \above the capital cost of the system itself which can run greater than $750,000. There is a clear indication that although the hardware continues to collect massive amounts of high information content; the software is significantly behind the curve with respect to managing, manipulating and extracting useful information for the point cloud.

Aerial LiDAR has the limitation of obscuration from overhead obstructions, trees, building overhangs, under bridges, and tunnels and the resolution does limit its application with respect to high detail feature requirements. However, it can map areas that the mobile or static scanners may have difficulty with access, such as residential backyards, private or restricted access property or wooded, remote areas with limited road or trail access. The post processing workflow and software tools are fairly mature and robust.

In comparison, static scanners can collect data densities on par or greater than the mobile sensors but the time and risk for the field collection adds cost and schedule with a point cloud the initial output source. These scanners are best suited for high accuracy and high detail in limited area project environments. For example deformation studies of bridge decks, individual scanning of joints, bolts, connections on bridges for engineering structural analysis.

The additional information content from the mobile platform is the “collect once use many times” model for data, extending use across multiple practitioners and organizations leveraging the “virtual survey” or “office survey” aspect for information extraction.

All the LiDAR systems can also be used at night limiting impact due to traffic congestion reducing “artifacts” in the data sets. This allows a potential compressed collection schedule due to the potential for 24 hr collection.

The static, mobile, and aerial LiDAR platforms will have areas where they seem to be the most appropriate choice. The appropriate usage of the three types of surveying techniques will also overlap based on various factors including cost, schedule, and the data required by potential end users of the survey. The potential use of the data that is collected during LiDAR surveys is wide ranging. Several examples are listed below:

- Flood Risk Mapping

[11] Graham L. Mobile Mapping Systems Overview PE&RS March 2010

- Utility Corridor Mapping/Planning
- Creek Bank Monitoring / Erosion Control
- Wetlands Mapping
- Disaster Response
- Airport/Airspace Mapping
- Roadway Corridor Mapping / EIS
- Roadway Improvement Projects
- Bridge Inspections / Replacements
- Intersection Enhancements
- Subsidence / Settlement Monitoring

Aerial LiDAR is usually most appropriate for Floodway mapping, utility and corridor mapping, and some disaster responses. Mobile LiDAR is usually most appropriate for high traffic areas, downtown urban environments, and corridor improvement projects. Static systems are generally suited towards the smaller enhancement projects.

There are more possible uses of the data that is collected depending on whether the information is shared across various agencies. The selection of the LiDAR method is not always a straight forward process. One important issue in selecting a LiDAR technique is to evaluate the future potential uses of the data. For example, if a corridor is in the planning phase for future improvements, you may want to use the Mobile LiDAR to scan the existing structures for use during inspections and scan the existing intersections to accommodate the survey needs for pedestrian enhancements or signal upgrades that are planned in the future.

The successful usage of LiDAR data collection techniques has been accomplished on previous projects. HDR utilized a static survey on the Rte. 61 bridge replacement over Establishment Creek in District 10. This technique was chosen in order to accurately depict a 50' tall rock face that existed at the southern abutment location. The LiDAR data was also used to delineate a forested wetland that existed on the northwest quadrant of the project. HDR also selected a static LiDAR survey for two bridge replacement projects in Franklin County. This method provided a very accurate bridge survey and creek channel mapping. A mobile LiDAR scan was performed on the Tucker Avenue Bridge Replacement project in downtown St. Louis. A scan of the existing tunnel section under the bridge provided detailed information on existing utility conduits, retaining walls, loading docks, and building foundations.

On a recent Interstate 55 contract in Jefferson County, median lane widening and bridge replacements were planned. This project is one of three projects in this corridor. This is a heavily traveled route, with a significant amount of trucks, and is fairly congested. The contract was funded with ARRA monies and was on a fast track schedule. A standard aerial survey was conducted on the project. This was a fairly lengthy process and was impacting the project schedule. A subsequent project was advertised for design and installation of an additional 10 miles of ITS infrastructure.

In reviewing the sequence of events along this corridor, a mobile LiDAR scan was probably warranted. Four separate projects could have been scanned at the same time. These improvements ranged from lane widening, roundabout, structure replacements, interchange ramps, and ITS infrastructure. Even though the timelines are several years in length, the survey would have been completed just once. This is the type of forward thinking that will help to lower the overall cost of the surveying tasks on projects. .

Sources of Error

Each step in any of the mapping or survey processes have the potential for human or instrument error to bias or corrupt the results of the project.
Key risk components include sensor calibration (ensure that all technologies) are maintained and calibrated in accordance with industry or manufacturer specifications as well as on-site or in-situ filed calibrations. Having independent checks for observations and calculations and outputs from automated processes must be built in each step of the process to minimize cost and schedule impacts. Something as simple as ensuring that all of the drawings contain the same working units and that the units.def file for all users of the data is in the same format. The units.def file is located on the local drive after Microstation is installed on a computer. The default layout of this file places international feet/inches ahead of survey feet/inches in the priority list. Problems arise when one end user is referring to a units.def file that is different than another user.

Aerial, Mobile and Static Lidar all meet or exceed the current accuracy requirements employed by traditional Aerial mapping, with advantages in data content potential, "virtual " office surveys, and collection of information currently collected using traditional field methods. However as the technology is evolving there are challenges in processing, and potential sources of error as noted above that must be planned for and designed into a processes to minimize errors in final data analysis.

Cost Comparison

As indicated in Table 10 Aerial and Mobile LiDAR has cost and information content advantages over conventional ground or static LiDAR surveys, but may not be the most cost effective method over traditional aerial surveys.

The key is to remember that the LiDAR collection technique is a potential tool that can be used and designers and project managers should consider it, even when the cost savings may be realized on a future project

Recommendations

The accuracy of the LiDAR data and the speed at which it can be collected is a major benefit to the end user. The keys to maximizing the value of this process lie within the MoDOT staff who will be working with these types of data sets on a regular basis. There are several recommendations that should be taken into consideration at the conclusion of this study.

1. MoDOT should develop individuals who are leaders in the area of LiDAR collection techniques. Due to the rapidly changing technology, it is essential to have staff dedicated to maintaining the high level of technical excellence that is demonstrated in other areas of operations.

2. MoDOT should develop procedures and deliverable standards for working with LiDAR survey data sets. This may include file types, file sizes, point codes, best practice, frequently asked questions, and typical issues that have arisen with this type of data. It is important that some standardization of the data sets take place in order to allow the process to become familiar to the end users, without limiting their ability to manipulate the data and tailor it to specific project needs.

3. MoDOT should consider upgrading to the current Microstation XM (08.09.04.88) and Geopak XM (08.09.07.28) in order to access the tools that have been developed to work in conjunction with LiDAR survey data sets.

4. MoDOT should seek out additional opportunities to implement LiDAR surveying techniques on projects. While not the best solution for all surveying needs, LiDAR surveys do provide benefits to the end user in terms of data and to the public in terms of reduction in traffic disruption during field work. These additional projects would also provide additional opportunities to expose MoDOT staff to this technology.

Implementation Plan

The method of implementing LiDAR collection techniques and training staff is critical in the overall success of this process. Significant enhancements to the capabilities of the MoDOT staff and considerable cost benefits can be realized through the use of this data. Listed below are the recommended methods for implementing the recommendations of this study.

1. MoDOT should develop individuals who are leaders in the area of LiDAR collection techniques. Staff development can take place via many different methods. Large scale training seminars, such as the TEAM conference, provide an opportunity to introduce the benefits of LiDAR surveys to a broad range of users. Lunch time seminars can provide a more detailed example of LiDAR surveying to a smaller group of individuals. Personalized training sessions can be attended for those staff members who are designated as individuals who will be leading MoDOT's efforts in the area of LiDAR surveying techniques.

2. MoDOT should develop procedures and deliverable standards for working with LiDAR survey data sets. A working group / steering committee should be established to direct the overall goals and objectives of the Department as it relates to implementing the usage of these data sets. This standardization would follow along the same paths as the Microstation and Geopak guidelines that are already published. This committee would also provide guidance and recommendations to project managers when determining the feasibility of utilizing LiDAR. This committee should also be tasked with evaluating the current MoDOT hardware and software standards and recommend areas where upgrades are applicable.

3. MoDOT should seek out additional opportunities to implement LiDAR surveying techniques on projects. MoDOT is currently in a state of tightening project budgets and maintaining the infrastructure that is in place. That has led to less large scale corridor development projects. Those projects remain in the planning phase and are scheduled for construction, but are dependent on future sources of funding. LiDAR surveying may help to provide some savings to projects that are currently in the planning phase. By using LiDAR techniques to survey current "maintenance" level projects, the higher accuracy data could be pulled from the database once a later "expansion" level project is funded. For example, if a future lane widening is planned along a corridor and ITS enhancement project is scheduled for surveying, it may be a cost savings to use LiDAR techniques in the ITS contract and pull that data from the shelf once the lane widening contract is funded.

   Another example of a project where enhanced collections efforts may be warranted is when Districts plan to workshare projects across District boundaries. A design team in District 2 working on a small bridge replacement project in District 10, could use the LiDAR data to limit trips to the field and save resources that could be dedicated to other uses.

Implementation Objective

The objectives of implementing LiDAR surveying techniques will focus on providing higher quality projects in a shorter amount of time, while utilizing less resources. Listed below are some of the benefits that can be realized through the implementation of the recommendations of this study.

1. **Safety enhancements:** LiDAR surveying techniques can provide a safer method of surveying a project corridor. Surveyors, motorists, and designers all will see an improvement in safety throughout the project corridor, during surveying operations and through the reduction in site visits and design field checks.

2. **Accuracy:** The accuracy and detail of the LiDAR survey allows for increased efficiency in the design phase of the project. The LiDAR survey allows for more accurate development of project profiles and for generation of more precise earthwork quantities. Another benefit of the LiDAR survey is that the end user has the ability to filter the data in order to best suit their needs. A highly, detailed survey has already been collected in the field. This level of accuracy can be tailored to meet the needs of the project via post processing. That process is not available through traditional methods of survey collection.

3. **Speed:** The speed of collection, especially mobile LiDAR, cannot be matched via traditional methods. The enhancement in speed of collection allows surveying tasks to be completed around constraints that restrict when certain activities may take place. For instance, the closure of a tunnel on a high volume route may not be possible. A mobile LiDAR survey could be conducted without disrupting traffic or a static LiDAR survey could be quickly completed with a minimal roadway closure time frame.

4. **Cost:** The reduction of costs is a key element in the implementation of any new technology. LiDAR surveys can help reduce construction change orders in earthwork quantities by providing a more accurate existing ground model. They can help to limit costs associated with design tasks by allowing existing sign surveys to be conducted from the office and assist in utility coordination by providing overhead clearances without having to conduct a separate field visit. The reduction of field work also saves user costs associated with traffic control and lane drops that are required to safely conduct field operations. Finally, as the LiDAR technology is utilized more frequently and by a wider range of companies, the overall cost to MoDOT will be lowered as the industry becomes more competitive.

5. **Knowledge:** The final benefit to the staff at MoDOT is the knowledge and expertise that comes with implementing these techniques. Staff members take pride in knowing that advanced technology and operations are being utilized in the completion of their design.

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Appendix A Control Report - Mobile Data

A total of 139 points were provided, 84 points were beyond the range of the mobile scanner and outside the area that was mapped (300 foot wide corridor from centerline of road.)

C:\Projects\MoDOT\MoDOT_Adjust_Control_28_June.pts

Number	Easting	Northing	Known Z	Laser Z	dz
100	675819.843	956830.290	589.937	590.080	+0.143
101	672594.330	959419.902	730.758	730.590	-0.168
102	672229.392	959886.600	739.758	739.580	-0.178
103	669360.917	963103.603	749.989	750.040	+0.051
104	668586.001	963356.133	746.529	746.500	-0.029
105	664512.056	964719.789	810.718	810.820	+0.102
106	664564.789	965658.647	801.845	801.950	+0.105
107	664048.014	970484.107	766.045	766.070	+0.025
108	663948.924	975720.992	761.436	761.750	+0.314
109	664470.975	976252.550	745.678	745.600	-0.078
110	670220.247	981057.825	675.429	675.490	+0.061
111	670439.937	981659.389	664.509	664.430	-0.079
112	671398.930	983895.342	644.127	644.190	+0.063
113	671692.053	984459.349	650.662	650.590	-0.072
114	663456.120	970499.958	748.731	outside	*
115	666592.348	978984.694	726.046	726.260	+0.214
116	666395.943	977593.561	706.947	706.830	-0.117
142	675906.275	956259.162	586.818	outside	*
300	677309.683	957516.223	581.487	outside	*
301	677141.577	956005.942	543.269	outside	*
302	676374.273	956993.638	564.863	564.810	-0.053
303	675691.964	957757.726	583.480	outside	*
304	675156.991	956847.522	626.337	626.250	-0.087
305	674620.217	957729.222	672.569	outside	*
306	674074.489	957064.723	649.747	649.850	+0.103
307	673818.059	955842.064	667.640	outside	*
308	672448.907	956368.863	602.900	outside	*
309	673470.524	957164.647	698.809	698.780	-0.029
310	672742.146	957992.525	627.001	outside	*
311	673345.149	960037.735	671.230	outside	*
312	671335.243	960083.866	689.568	outside	*
313	671531.866	961812.187	694.567	outside	*
314	670813.886	962401.602	755.699	755.810	+0.111
315	671364.696	963237.761	773.830	outside	*
316	670460.591	963229.993	768.341	768.350	+0.009
317	670786.776	964174.576	744.950	outside	*
318	669360.917	963103.603	750.190	750.040	-0.150
319	668919.660	964245.323	690.317	outside	*
320	667530.940	963079.758	715.593	outside	*
321	666370.368	964861.177	744.701	outside	*
322	665264.946	963589.796	735.536	outside	*

323	664766.784	964419.895	785.906	786.180	+0.274
324	663967.094	963687.741	783.614	outside	*
325	664221.855	965337.774	784.241	outside	*
326	665394.855	966673.475	795.498	outside	*
327	663962.764	968026.046	789.434	outside	*
328	665182.761	969074.632	735.273	outside	*
329	663568.034	970127.709	758.815	outside	*
330	664811.072	971439.667	704.417	outside	*
331	663327.347	972103.039	763.185	outside	*
332	664813.637	973284.809	772.698	outside	*
333	664218.060	974517.220	757.299	757.360	+0.061
334	663137.236	975835.862	742.457	outside	*
335	664095.476	975822.876	754.598	754.650	+0.052
336	664470.975	976252.550	745.668	745.600	-0.068
337	663298.631	977167.272	701.004	outside	*
338	664744.756	977405.227	690.624	outside	*
339	666746.710	977113.277	689.126	outside	*
340	666677.161	978940.356	722.564	722.680	+0.116
341	668673.841	978875.590	695.440	outside	*
342	668615.121	979618.291	672.772	outside	*
343	667737.606	979823.856	693.854	outside	*
344	669636.814	980012.394	698.960	699.020	+0.060
345	668374.933	980925.526	666.609	outside	*
346	668973.679	981615.713	674.617	outside	*
347	671065.416	981894.355	617.419	outside	*
348	670557.023	983418.776	604.646	outside	*
349	671291.654	983839.529	643.984	644.180	+0.196
350	672495.353	983916.044	591.437	outside	*
351	671135.421	984715.332	584.529	outside	*
500	671775.766	984556.324	652.282	652.250	-0.032
501	670671.174	982696.837	649.162	649.140	-0.022
502	669614.117	982302.138	629.278	outside	*
503	669897.726	981471.236	616.513	outside	*
504	667735.745	978964.684	717.749	717.780	+0.031
505	672271.866	983479.810	573.964	outside	*
506	671331.216	983452.122	654.441	654.390	-0.051
507	670109.964	983304.918	583.125	outside	*
508	669775.443	980173.814	693.705	693.650	-0.055
509	669287.861	980782.086	628.900	outside	*
510	668177.043	980630.801	698.808	outside	*
511	668475.655	979614.444	664.877	outside	*
512	668638.021	979161.125	710.611	710.500	-0.111
513	666585.716	979062.732	733.353	733.520	+0.167
514	666556.502	978060.198	676.394	676.570	+0.176
515	666744.366	977091.960	692.951	outside	*
516	665838.636	976991.811	734.931	734.820	-0.111
517	664666.108	977419.912	689.041	outside	*
518	663203.968	977230.986	700.713	outside	*
519	662876.081	975730.756	744.500	outside	*
520	664088.890	975826.410	756.061	755.970	-0.091

521	665192.204	975947.270	701.389	outside	*
522	664128.058	974924.102	765.835	765.780	-0.055
523	664929.920	974004.131	733.182	outside	*
524	663403.297	973550.902	772.469	outside	*
525	664175.594	972812.110	781.362	781.260	-0.102
526	663330.143	972098.004	763.617	outside	*
527	665217.096	971468.960	723.113	outside	*
528	664222.329	970598.397	762.022	762.360	+0.338
529	663466.488	970209.396	751.439	outside	*
530	664189.654	969750.119	767.311	767.230	-0.081
531	665172.790	969091.843	737.046	outside	*
532	664599.540	968558.619	771.172	771.030	-0.142
533	664258.701	968044.579	794.019	outside	*
534	664767.520	967300.751	784.280	784.170	-0.110
535	663769.202	966774.291	787.874	outside	*
536	665487.890	966677.877	792.051	outside	*
537	664660.020	966036.048	798.228	798.270	+0.042
538	663968.704	965369.586	759.765	outside	*
539	665090.504	965075.540	797.330	outside	*
540	664689.471	964432.725	795.156	795.160	+0.004
541	664039.918	963938.617	784.852	outside	*
542	665174.025	963504.821	739.827	outside	*
543	665765.844	965021.929	770.072	outside	*
544	666667.076	964891.724	731.378	outside	*
545	666945.639	963731.860	751.883	outside	*
546	667546.036	962934.784	706.163	outside	*
547	668480.085	964425.116	707.739	outside	*
548	669482.916	963082.494	753.565	753.500	-0.065
549	670413.792	961635.243	707.433	outside	*
550	670499.593	963166.655	766.433	766.390	-0.043
551	670785.847	964250.398	742.244	outside	*
552	671373.706	963343.437	776.577	outside	*
553	670850.046	962370.619	758.194	758.040	-0.154
554	671970.278	961967.726	677.621	outside	*
555	670748.817	960977.133	726.912	outside	*
556	671914.563	960648.199	756.893	outside	*
557	671370.411	959811.148	663.860	outside	*
558	672261.475	959851.527	738.686	738.510	-0.176
559	673435.160	959892.273	655.287	outside	*
560	672783.734	959242.455	727.662	727.530	-0.132
561	672501.797	958151.883	636.394	outside	*
562	673474.543	957222.723	700.526	700.450	-0.076
563	674282.464	956772.808	631.740	outside	*
564	674580.217	958099.087	685.905	outside	*
565	673767.278	955776.833	674.521	outside	*
566	675540.481	956828.730	603.556	603.360	-0.196
567	676373.422	956027.223	572.222	outside	*
568	677144.181	957486.755	592.614	outside	*

Average dz -0.002

Minimum dz	-0.196
Maximum dz	+0.338
Average magnitude	0.104
Root mean square	0.126
Std deviation	0.128

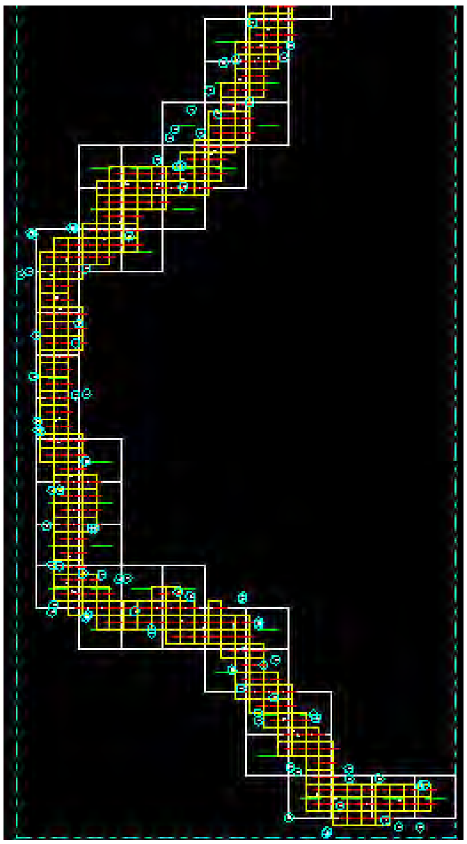

Figure 44 Points outside of coverage (blue)

The points in blue were outside of the aerial or mobile data coverage's at time of collection

Figure 45 Point 345

Figure 46 Point 347

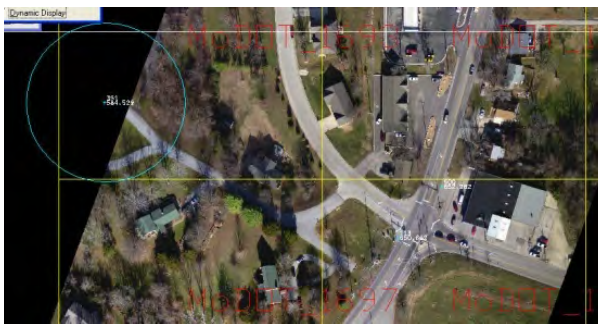

Figure 47 Point 351

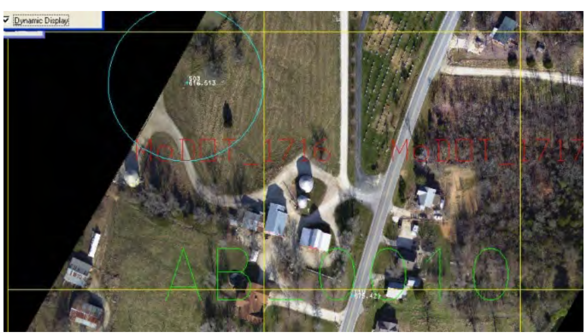

Figure 48 Point 503

Appendix A Control Report - Aerial Data

A total of 139 points were provided, 73 points were outside the area that was mapped (300 foot wide corridor from centerline of road)

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Number	Easting	Northing	Known Z	Laser Z	dz
100	675819.843	956830.290	589.937	590.180	+0.243
101	672594.330	959419.902	730.758	730.640	-0.118
102	672229.392	959886.600	739.758	739.790	+0.032
103	669360.917	963103.603	749.989	750.040	+0.051
104	668586.001	963356.133	746.529	746.370	-0.159
105	664512.056	964719.789	810.718	810.740	+0.022
106	664564.789	965658.647	801.845	801.960	+0.115
107	664048.014	970484.107	766.045	766.050	+0.005
108	663948.924	975720.992	761.436	761.610	+0.174
109	664470.975	976252.550	745.678	745.560	-0.118
110	670220.247	981057.825	675.429	675.420	-0.009
111	670439.937	981659.389	664.509	664.500	-0.009
112	671398.930	983895.342	644.127	644.160	+0.033
113	671692.053	984459.349	650.662	650.660	-0.002
114	663456.120	970499.958	748.731	outside	*
115	666592.348	978984.694	726.046	726.150	+0.104
116	666395.943	977593.561	706.947	706.920	-0.027
142	675906.275	956259.162	586.818	outside	*
300	677309.683	957516.223	581.487	outside	*
301	677141.577	956005.942	543.269	outside	*
302	676374.273	956993.638	564.863	outside	*
303	675691.964	957757.726	583.480	outside	*
304	675156.991	956847.522	626.337	626.410	+0.073
305	674620.217	957729.222	672.569	outside	*
306	674074.489	957064.723	649.747	649.820	+0.073
307	673818.059	955842.064	667.640	outside	*
308	672448.907	956368.863	602.900	outside	*
309	673470.524	957164.647	698.809	698.940	+0.131
310	672742.146	957992.525	627.001	outside	*
311	673345.149	960037.735	671.230	outside	*
312	671335.243	960083.866	689.568	outside	*
313	671531.866	961812.187	694.567	outside	*
314	670813.886	962401.602	755.699	755.820	+0.121
315	671364.696	963237.761	773.830	outside	*
316	670460.591	963229.993	768.341	768.290	-0.051
317	670786.776	964174.576	744.950	outside	*
318	669360.917	963103.603	750.190	750.040	-0.150
319	668919.660	964245.323	690.317	outside	*
320	667530.940	963079.758	715.593	outside	*
321	666370.368	964861.177	744.701	outside	*
322	665264.946	963589.796	735.536	735.220	-0.316
323	664766.784	964419.895	785.906	786.150	+0.244
324	663967.094	963687.741	783.614	outside	*
325	664221.855	965337.774	784.241	784.260	+0.019
326	665394.855	966673.475	795.498	outside	*
327	663962.764	968026.046	789.434	outside	*
328	665182.761	969074.632	735.273	outside	*

329	663568.034	970127.709	758.815	outside	*
330	664811.072	971439.667	704.417	outside	*
331	663327.347	972103.039	763.185	outside	*
332	664813.637	973284.809	772.698	outside	*
333	664218.060	974517.220	757.299	757.410	+0.111
334	663137.236	975835.862	742.457	outside	*
335	664095.476	975822.876	754.598	754.810	+0.212
336	664470.975	976252.550	745.668	745.560	-0.108
337	663298.631	977167.272	701.004	outside	*
338	664744.756	977405.227	690.624	outside	*
339	666746.710	977113.277	689.126	689.280	+0.154
340	666677.161	978940.356	722.564	722.620	+0.056
341	668673.841	978875.590	695.440	695.560	+0.120
342	668615.121	979618.291	672.772	672.720	-0.052
343	667737.606	979823.856	693.854	outside	*
344	669636.814	980012.394	698.960	699.050	+0.090
345	668374.933	980925.526	666.609	outside	*
346	668973.679	981615.713	674.617	outside	*
347	671065.416	981894.355	617.419	617.220	-0.199
348	670557.023	983418.776	604.646	outside	*
349	671291.654	983839.529	643.984	644.160	+0.176
350	672495.353	983916.044	591.437	outside	*
351	671135.421	984715.332	584.529	outside	*
500	671775.766	984556.324	652.282	652.310	+0.028
501	670671.174	982696.837	649.162	648.690	-0.472
502	669614.117	982302.138	629.278	outside	*
503	669897.726	981471.236	616.513	outside	*
504	667735.745	978964.684	717.749	717.610	-0.139
505	672271.866	983479.810	573.964	outside	*
506	671331.216	983452.122	654.441	654.050	-0.391
507	670109.964	983304.918	583.125	outside	*
508	669775.443	980173.814	693.705	693.690	-0.015
509	669287.861	980782.086	628.900	outside	*
510	668177.043	980630.801	698.808	outside	*
511	668475.655	979614.444	664.877	664.670	-0.207
512	668638.021	979161.125	710.611	710.700	+0.089
513	666585.716	979062.732	733.353	733.180	-0.173
514	666556.502	978060.198	676.394	676.470	+0.076
515	666744.366	977091.960	692.951	693.100	+0.149
516	665838.636	976991.811	734.931	734.820	-0.111
517	664666.108	977419.912	689.041	outside	*
518	663203.968	977230.986	700.713	outside	*
519	662876.081	975730.756	744.500	outside	*
520	664088.890	975826.410	756.061	755.790	-0.271
521	665192.204	975947.270	701.389	outside	*
522	664128.058	974924.102	765.835	765.930	+0.095
523	664929.920	974004.131	733.182	outside	*
524	663403.297	973550.902	772.469	outside	*
525	664175.594	972812.110	781.362	781.430	+0.068
526	663330.143	972098.004	763.617	outside	*
527	665217.096	971468.960	723.113	outside	*
528	664222.329	970598.397	762.022	762.340	+0.318
529	663466.488	970209.396	751.439	outside	*
530	664189.654	969750.119	767.311	767.320	+0.009
531	665172.790	969091.843	737.046	outside	*
532	664599.540	968558.619	771.172	771.090	-0.082

533	664258.701	968044.579	794.019	793.580	-0.439
534	664767.520	967300.751	784.280	784.200	-0.080
535	663769.202	966774.291	787.874	outside	*
536	665487.890	966677.877	792.051	outside	*
537	664660.020	966036.048	798.228	798.360	+0.132
538	663968.704	965369.586	759.765	outside	*
539	665090.504	965075.540	797.330	outside	*
540	664689.471	964432.725	795.156	795.310	+0.154
541	664039.918	963938.617	784.852	outside	*
542	665174.025	963504.821	739.827	outside	*
543	665765.844	965021.929	770.072	outside	*
544	666667.076	964891.724	731.378	outside	*
545	666945.639	963731.860	751.883	751.660	-0.223
546	667546.036	962934.784	706.163	outside	*
547	668480.085	964425.116	707.739	outside	*
548	669482.916	963082.494	753.565	753.630	+0.065
549	670413.792	961635.243	707.433	outside	*
550	670499.593	963166.655	766.433	766.320	-0.113
551	670785.847	964250.398	742.244	outside	*
552	671373.706	963343.437	776.577	outside	*
553	670850.046	962370.619	758.194	757.830	-0.364
554	671970.278	961967.726	677.621	outside	*
555	670748.817	960977.133	726.912	outside	*
556	671914.563	960648.199	756.893	757.110	+0.217
557	671370.411	959811.148	663.860	outside	*
558	672261.475	959851.527	738.686	738.560	-0.126
559	673435.160	959892.273	655.287	outside	*
560	672783.734	959242.455	727.662	727.710	+0.048
561	672501.797	958151.883	636.394	outside	*
562	673474.543	957222.723	700.526	700.560	+0.034
563	674282.464	956772.808	631.740	631.420	-0.320
564	674580.217	958099.087	685.905	outside	*
565	673767.278	955776.833	674.521	outside	*
566	675540.481	956828.730	603.556	603.320	-0.236
567	676373.422	956027.223	572.222	outside	*
568	677144.181	957486.755	592.614	outside	*

Average dz -0.019
Minimum dz -0.472
Maximum dz +0.318
Average magnitude 0.135
Root mean square 0.173
Std deviation 0.173

Common Missing Points

MoDOT Point 568 -Ground Shot- well outside of both Mobile and aerial coverage scope including Centerline and Buffer File.
MoDOT Point 567 -Asphalt- well outside of Project scope centerline and buffer.
MoDOT Point 565 -Asphalt- well outside of Project scope centerline and buffer.
MoDOT Point 564 -Cul-de Sac- Outside of Project scope centerline and buffer.
MoDOT Point 563 -Edge of Pavement- Outside of Mobile data scan
MoDOT Point 561 -Corner concrete- Outside of Project scope centerline and buffer.
MoDOT Point 559 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 557 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 556 -CL Gravel- Outside of Mobile data scan
MoDOT Point 555 -CL Gravel- Outside of Mobile data scan
MoDOT Point 554 -Corner concrete- Outside of Project scope centerline and buffer.
MoDOT Point 552 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 551 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 549 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 547 -Edge of Pavement- Outside of Mobile data scan
MoDOT Point 546 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 545 -Edge of Pavement- Mobile Obscuration.
MoDOT Point 544 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 543 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 542 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 541 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 539 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 538 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 536 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 535 -Edge of Pavement- Outside of Mobile data scan
MoDOT Point 533 -Edge of Pavement- Outside of Mobile data scan
MoDOT Point 531 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 529 -Corner concrete- Outside of Project scope centerline and buffer.
MoDOT Point 527 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 526 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 524 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 523 -CL Rod- Outside of Mobile data scan
MoDOT Point 521 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 519 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 518 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 517 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 515 -Ground Shot- Outside of Project scope centerline and buffer.
MoDOT Point 511 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 510 -Edge of Pavement- Outside of Project scope centerline and buffer.
MoDOT Point 509 -CL Gravel- Outside of Project scope centerline and buffer.

MoDOT Point 507 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 505 -Corner concrete- Outside of Project scope centerline and buffer.
MoDOT Point 503 -CL Gravel- Outside of Mobile data scan
MoDOT Point 502 -CL Gravel- Outside of Project scope centerline and buffer.
MoDOT Point 351 -Panel Point- Outside of Mobile scan data
MoDOT Point 350 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 348 -Panel Point- Outside of Mobile scan data
MoDOT Point 347 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 345 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 343 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 342 -Panel Point- Outside of Mobile data scan
MoDOT Point 341 -Panel Point- Outside of Mobile data scan
MoDOT Point 339 -Panel Point- Outside of Mobile data scan
MoDOT Point 338 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 337 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 334 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 332 -Panel Point- Outside of Mobile data scan
MoDOT Point 331 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 330 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 329 -Panel Point- Outside of Mobile data scan
MoDOT Point 328 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 327 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 326 -Panel Point- Outside of Mobile data scan
MoDOT Point 325 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 322 -Panel Point- Outside of Mobile data scan
MoDOT Point 321 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 320 -Panel Point- Outside of Mobile data scan
MoDOT Point 319 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 317 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 315 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 313 -Panel Point- Outside of Mobile scan data
MoDOT Point 312 -Panel Point- Outside of Mobile scan data
MoDOT Point 311 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 310 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 308 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 307 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 305 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 303 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 301 -Panel Point- Outside of Project scope centerline and buffer.
MoDOT Point 300 -Panel Point- Outside of Project scope centerline and buffer and Mobile data scan.
MoDOT Point 142 -Mon FR-25a- Outside of Mobile data scan
MoDOT Point 114 -Mon FR-23a- Outside of Project scope centerline and buffer.

APPENDIX B SURVEY REPORT

EFK•Moen, LLC

Civil Engineering Design

Job # J6S2194
Route A,
Franklin County, Missouri
December 28, 2009

The site is Route A in Franklin County, Missouri between Union Missouri and Washington Missouri. This Route has a previous MODOT project no. of J6S2194, further to be referred to as (site). In March 2009 MODOT had horizontal and vertical control set on the project for Aerial topography mapping purposes. A report for this March 2009 control network was submitted May 27, 2009 by Raymond C. Armstrong, PLS of Hanson Professional Services, Inc. Further reference to the values submitted by this May 2009 report will be **(MODOT Values)**. References to values of control and panel points obtained by EFK Moen, LLC during December 2009 will be referred to as **(EFK Values).** References to values of NGS control stations obtained from the National Geodetic Survey and reported to be on the National Spatial Reference System, NSRS2007 will be referred to as **(USGS Published Values)**.

The purpose of this report is to verify that the MODOT values of the site survey control network is still in compliance with the MODOT control survey requirements, as they were reported to be, for photogrammetric, aerial photography and targeting. In my opinion the most timely and economical manner in which to accomplish this goal was to use the MODOT GPS reference station network using the following methods and equipment .

13523 Barrett Pky Dr., Suite 250
St. Louis, MO 63021
Phone: 314.729.4100
Fax: 314.729.4199

331 Salem Place, Suite 225
Fairview Heights, IL 62208
Phone: 618.206.4250
Fax: 618.206.4253

1911 S. National Ave., Suite 404
Springfield, MO 65804
Phone: 417.447.3271
Fax: 417.447.3274

Implemented equipment:

TDS Nomad collector software version 1.0.3
Epoch 35 Antenna, cell freq. 450-470 MHz

Implemented methods:

- Re-establish MODOT GPS reference station network (VRS) values on site.
- Locate and tie at least 4 NGS stations as originally used in March 2009 and report (USGS published values) (MODOT Values) (EFK Values).
- Locate and tie both site control & panel control points at both North and South end of site and along interior of site. Report (MODOT Values) (EFK Values).
- Locate and tie vertical control points to site control network using same differential level methods as used in March 2009. Report (MODOT Values) and (EFK Values).
- This report includes a chart showing final values reported by MODOT in May 2009, values of observations taken December 2009, and the values of published NGS control stations.

General facts concerning site:

- Common Horizontal NGS Monument points used were FR 31, FR 88, FR 25, and FR 23.
- Common Vertical NGS Monument control points used were T334, J339.
- The conventional level loop was checked holding the elevations of NGS Monuments T334 and J339, and the VRS values of observed stations.
- The horizontal datum is referenced to NAD 83 (2007).

- The vertical datum is referenced to NAVD 88.
- The projection Factor is 1.000074867.
- The grid Factor is 0.999925138.
- State Plane Coordinates are Missouri East Zone Coordinate System of 1983 and expressed in US Survey Feet.

Certification

The horizontal coordinates were established and verified by GPS observations through the use of a cellular device equipped Epoch Model 35 GNSS Rover and a TDS Nomad Controller utilizing the Missouri Highways and Transportation Commission Global Navigation Satellite Real Time Network for Continuous Operating Stations. This information was adopted and checked by field GPS observations to two (2) NAD83(NSRS2007) adjusted points. Field observed check stations were as follows; FR-20 with a NGS NGS PID (Permanent Identifier) of AC6167, FR-23 with a NGS PID of AC6170, FR-25 with a NGS PID of AC6172, FR-31 with a NGS PID of AC6178 and FR88 with a NGS PID of AC6234. The site grid azimuth and project grid factor were adopted as calculated by the TDS Nomad survey controller software. The Missouri East Zone NAD83(NSRS2007) state plane grid coordinates for the control points were adopted as calculated by the TDS Nomad survey controller software. To the best of our knowledge, the calculated state plane grid coordinates meet the accuracy standards of the current Missouri minimum standards for property boundary surveys (20 csr 2030-16) as an urban class survey relative to stations FR-20, FR-23, FR-25, FR-31, and FR88.

FRANKLIN COUNTY MISSOURI ROUTE A
ROUTE 100 TO ROUTE 47
JOB#J6S2194

MAPPING STATE PLANE COORDINATES
MO EAST ZONE
HORIZ. DATUM: NAD 83(2007)
GRID FACTOR: 0.999925138
PROJECTION FACTOR: 1.000074867
UNITS: U.S. SURVEY FEET

PT ID		(MODOT VALUES)	USGS PUBLISHED VALUE	(EFK VALUES) 12-16-09	(EFK VALUES) 12-17-09	AVERAGE EFK VALUES	DIFFERENTIAL
25a	N	956187.575		956187.587	SANBORN	956187.587	-0.012
	E	675855.675		675855.669	BASE	675855.669	0.006
103	N	963031.503		963031.516	963031.444	963031.480	0.023
	E	669310.807		669310.833	669310.838	669310.836	-0.029
109	N	976179.466		976179.518	976179.507	976179.513	-0.046
	E	664421.231		664421.168	664421.210	664421.189	0.042
112	N	983821.686		983821.769	983821.769	983821.769	-0.083
	E	671348.668		671348.686	671348.686	671348.686	-0.018
113	N	984385.650		984385.719	SANBORN	984385.719	-0.069
	E	671641.769		671641.756	BASE	671641.756	0.013
173	N			952356.335	952356.311	952356.323	
	E			661766.967	661766.955	661766.961	
302	N	956921.996		956921.996	956921.975	956921.986	0.011
	E	676323.638		676323.624	676323.586	676323.605	0.033
307	N	955770.508		955770.587	955770.520	955770.554	-0.046
	E	673767.616		673767.569	673767.574	673767.572	0.044
324	N	963615.597		963615.637	963615.606	963615.622	-0.025
	E	663917.388		663917.353	663917.392	663917.373	0.015
330	N	971366.943		971366.979	971366.960	971366.970	-0.027
	E	664761.303		664761.295	664761.260	664761.278	0.025
337	N	977094.119		977094.167	977094.174	977094.171	-0.052
	E	663248.975		663248.927	663248.896	663248.912	0.064

351	N	984641.614		984641.641	984641.671	984641.656	-0.042
	E	671085.178		671085.184	671085.157	671085.171	0.007
FR 20	N		991564.434	991564.623	991564.644	991564.634	-0.199
	E		664795.061	664795.118	664795.128	664795.123	-0.062
FR 23	N		970427.305	970427.318	970427.297	970427.307	-0.002
	E		663406.452	663406.453	663406.443	663406.448	0.004
FR 25	N		954900.069	954900.060	954900.067	954900.063	0.006
	E		676308.897	676308.881	676308.921	676308.901	-0.004
FR 31	N		969130.847	969130.868	969130.899	969130.883	-0.036
	E		706854.544	706854.572	706854.569	706854.570	-0.026
FR 88	N		978911.405	978911.461	978911.481	978911.471	-0.066
	E		666542.446	666542.456	666542.516	666542.486	-0.040

STATE OF MISSOURI
MARK E. COLLINS
NUMBER
PLS-2006000173
PROFESSIONAL LAND SURVEYOR

1/14/10

FRANKLIN COUNTY MISSOURI ROUTE A
ROUTE 100 TO ROUTE 47
JOB#J6S2194

ELEVATION DIFFERENTIALS
VERT. DATUM: NAVD88
UNITS: U.S. SURVEY FEET

STATE OF MISSOURI
MARK E. COLLINS
NUMBER
PLS-2006000173
PROFESSIONAL LAND SURVEYOR

PT ID	(MODOT VALUES)	(EFK VALUES) 12-16-09	(EFK VALUES) 12-17-09	AVERAGE EFK VALUES	DIFFERENTIAL
25a	586.81	586.65	SANBORN BASE	586.64	0.17
103	749.99	749.89	749.97	749.93	0.06
109	745.68	745.67	745.67	745.67	0.01
112	644.10	644.08	644.08	644.08	0.02
113	650.66	650.67	SANBORN BASE	650.67	-0.01
173	718.87	718.75	718.75	718.75	0.12
302	564.86	564.84	564.81	564.82	0.04
307	667.64	667.60	667.64	667.62	0.02
324	783.61	783.60	783.60	783.60	0.01
330	704.42	704.45	704.49	704.47	-0.05
337	701.00	701.07	701.02	701.04	-0.04
351	584.53	584.66	584.63	584.65	-0.12
FR 20	511.76	511.74	511.71	511.72	0.04
FR 23	748.73	748.65	748.75	748.70	0.03
FR 25	543.62	543.57	543.53	543.55	0.07
FR 31	656.31	656.31	656.30	656.30	0.01
FR 88	726.04	726.03	725.97	726.00	0.04

Missouri Department of Transportation
Organizational Results
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